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Keywords
Calibrated Peer Review, writing-to-learn, t-test analyses

Disciplines
Earth Sciences | Educational Assessment, Evaluation, and Research | Educational Methods | Geology | Higher Education

Comments
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Calibrated Peer Review Assignments for the Earth Sciences

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ABSTRACT

Calibrated Peer Review ™ (CPR), a web-based instructional tool developed as part of the National Science Foundation reform initiatives in undergraduate science education, allows instructors to incorporate multiple writing assignments in large courses without overwhelming the instructor. This study reports successful implementation of CPR in a large, introductory geology course and student learning of geoscience content. For each CPR assignment in this study, students studied web-based and paper resources, wrote an essay, and reviewed seven essays (three from the instructor, three from peers, and their own) on the topic. Although many students expressed negative attitudes and concerns, particularly about the peer review process of this innovative instructional approach, they also recognized the learning potential of completing CPR assignments. Comparing instruction on earthquakes and plate boundaries using a CPR assignment vs. an instructional video lecture and homework essay with extensive instructor feedback, students mastered more content via CPR instruction.

BACKRGOUND

In the 1996 National Science Education Standards, the National Research Council emphasized the importance of scientific literacy for all and the need for drastic changes in science education (NRC, 1996). One of their major calls was for students to engage in more explanation and communication of science to enhance their scientific understanding by combining content knowledge with thinking skills. Writing-to-learn instructional strategies have been reviewed for their potential to improve content understanding and attitudes in science students (Rivard, 1994; Yore, 2003; Prain, 2006). Writing activities in science instruction can engage students in a wide range of knowledge transformation (Bereiter and Scardamalia, 1987; Holliday et al., 1994; Keys, 1999) and knowledge representation (Halliday and Martin, 1993; Kelly and Chen, 1999) learning processes, and reports have shown improved content understanding and attitudes towards science (Moore, 1993; Hanrahan, 1999; Pelaez, 2002; Hohenshell, 2006; Akkus et al., 2007; Rudd et al., 2007).

Indeed, geoscience educators have applied significant efforts toward incorporating writing assignments into geoscience instruction, including the publication of an entire issue of the Journal on writing in the classroom (Journal of Geological Education, 1991). Writing assignments, however, are often limited to small classes (Wells, 1997; Mango, 2000; Rankey, 2003; Peck, 2004; Bank, 2006; Leydens and Santi, 2006), such as upper division classes of 20 or fewer students, and when implemented in large classes, instructors face significant challenges structuring assignments that engage students in-depth with geoscience concepts (Peters, 1996; Wells, 1997; Takao et al., 2002; Peck, 2004). When grading student written work, instructors rarely have time to give useful and constructive feedback on each individual's content misunderstandings and writing style (Peters, 1996; Peterson et al., 1996; Wells, 1997; Mango, 2000; Takao et al., 2002; Rankey, 2003; Peck, 2004; Bank, 2006; Leydens and Santi, 2006), and writing assignments are usually omitted entirely from large, introductory classes because of these practical constraints. Furthermore, students are rarely exposed to another important scholarly skill, the peer review process, and such training may not occur until their graduate studies, if at all. Today's educational technology can greatly assist instructors with implementing the elements of writing and peer review into large enrollment, introductory-level, science classes, and may have the ability to expand the scope of writing to learn in science (Yore, 2003; Prain, 2006; Prothero and Kelly, 2008).

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CALIBRATED PEER REVIEW

Calibrated Peer Review™ (CPR) is a web-based instructional tool that allows integration of multiple writing assignments in large courses without overburdening the instructor (Russell et al., 1998; Stokstad, 2001). CPR was developed by chemistry faculty from six California institutions, as part of the Molecular Science Project (see http://www.molsci.ucla.edu), one of the chemistry systemic reform initiatives supported by the National Science Foundation's Division of Undergraduate Education (Russell, 1997; Burke et al., 2002; Burke et al., 2004). Although most widely used by chemistry and biology instructors to date, CPR succeeds in a variety of disciplines, class sizes, and instructional levels. CPR has been used by more than 1100 institutions in more than 4400 courses, including chemistry (Russell and Pearson, 2004; Margerum et al., 2007), biology (Robinson, 2001; Pelaez, 2002; Gerdeman et al., 2007), engineering (Carlson and Berry, 2003), neuroscience (Prichard, 2005), rhetoric (Carlson and Berry, 2003), and business (Plutsky and Wilson, 2004). With CPR, students write on and critically review important course topics via a web-based assignment and management system. Students gain content understanding (Pelaez, 2002), writing ability (Plutsky and Wilson, 2004; Gerdeman et al., 2007), peer reviewing ability (Plutsky and Wilson, 2004; Gerdeman et al., 2007), and self-reflection ability (Gerdeman et al., 2007).

In addition, CPR allows an instructor to create and store writing assignments using the same web-based

system. The CPR project supports regional and national workshops at universities and colleges across the nation to disseminate this instructional tool and to train instructors on implementation and authoring of assignments (see http://www.molsci.ucla.edu/workshops/upcoming.html for workshop schedule). Currently, CPR users have authored over 1800 assignments, including 455 chemistry, 330 biology, and 50 Earth systems assignments, and many of them are available to instructors through the UCLA CPR server library.

Students complete a CPR assignment in four main stages, and the program manages students' input, including written work and reviews, for each stage and the overall assignment. In the first stage, students study source material, write according to instructor guidelines, and submit their written work, usually an essay, to the web-based program. In stages two and three, students review example essays created by the instructor and, in an anonymous fashion, review three essays submitted by classmates. In the last stage, students self-review the essay they each originally submitted.

This paper describes the creation and implementation of a prototype CPR assignment in an introductory geology class and presents data on student learning and student responses to CPR. Specifically, we investigated the instructional effectiveness of a CPR assignment on earthquakes as compared to an alternative writing assignment as measured by student content understanding on multiple-choice and essay exam questions.

METHODS

In designing the prototype assignment, we chose the topic of earthquakes, one of the most engaging and discussed topics in introductory geology classes. Because of past student responses on essays and exams, we targeted misconceptions regarding the relationship between plate motions and earthquake depth and location.

We produced a CPR assignment titled "Earthquakes and Plate Boundaries" and utilized a quasi-experimental design involving two large-enrollment sections (control and treatment sections) of the same course (Geology 100 - The Earth) taught by the same instructor at a large U.S. Midwestern state university (Cervato et al., 2003). Initial enrollment in each section was approximately 250 students, and as a measure of baseline ability in the course, both sections were given a diagnostic test (Cervato et al., 2007) in the first week of classes. To provide both sections practice in answering essay questions prior to assessing students through essay questions on the exams, both sections were introduced to CPR in the first week, and they were assigned two CPR assignments from UCLA's CPR library, "Why Study Geology?" (Heise et al., 2002) due at the end of Week 1 and "Significant Figures" (Eikey, 2003) due in Week 7. After each assignment ended, the instructor gave both sections the same hour-long exam as a normal part of the course. The first exam consisted only of multiple-choice questions while the second also included four short answer and essay questions. To assess the instructional effectiveness of a CPR assignment on earthquakes, Section 1 was assigned a third CPR assignment, "Earthquakes and Plate Boundaries" in Week 12 but did not receive any lecture instruction on this topic. Section 2, however, viewed an instructional video and was assigned a homework essay that was returned with extensive instructor feedback. The alternative instruction in Section 2 was intended to provide those students with similar time on the topic, including writing practice, as students in Section 1 in order to strengthen the comparative assessment of student content understanding on the topic. Other than these differences regarding the third CPR assignment vs. alternative essay assignment, all other course instruction for the two sections was the same as much as possible. The assignment was followed by a third exam that included multiple-choice and essay questions directly related to the topic of earthquakes and plate boundaries. Section 1 and 2 student scores on these questions were quantitatively compared using t-test analyses. The essay responses were rated by three graders and averaged to reduce bias, and the inter-rater reliability coefficient (Shrout and Fleiss, 1979) of 0.91 indicated strong agreement among the three raters. Statistical analyses were completed using only those cases that had complete data sets, which consisted of the students completing the homework assignment (CPR or essay), taking the third exam, and finishing the course, which was defined as taking the final exam and receiving a course grade. After eliminating students who dropped the course or missed the homework assignment, the third exam, and/or the final exam, Section 1 had 150 students and Section 2 had 153 students with complete data sets.

CREATING CPR ASSIGNMENTS

The production of a CPR assignment involves multiple steps that can require several days to finish but can be completed in any order. Generally, the author, typically the instructor who wants to implement a CPR assignment, first selects an assignment topic, goals, and appropriate source material, such as web-based reading material, simulations, and/or tutorials, as well as other material for students to review prior to writing their essays. Web-based resources make the assignment less dependent on a specific textbook. Box 1 shows the assignment goals and source material in the CPR format for the example assignment presented in this paper. The author then drafts specific instructions for studying each source, broad guiding questions for student learning and integration of the overall content of the assignment, and a writing prompt. Often the author revises the initial instructions and questions after completing the next step, the creation of example essays.

CPR assignments utilize three example essays (called calibration essays) for students to review and score as a way to calibrate and improve their reviewing ability prior to scoring peer-written essays. The instructor creates an example essay that demonstrates high-quality content and style (i.e., an ideal answer), one middle-quality essay, and one low-quality essay. The high-quality calibration essay fulfills all the content requirements of the assignment in a clear, grammatically correct and concise writing style. The

other two calibration essays possess lesser quality and contain misconceptions often found in student exam responses. Students critically read and review the example essays according to instructor guidelines in order to develop their reviewing ability and understanding of the material, and the varying essay quality gives students multiple contexts to analyze for strong and weak points.

Ideally, past student responses should be used or modified for these calibration essays because it can be difficult to mimic student style and phrasing for misconceptions, and an instructor's writing style can allow students to perceive quickly the "right answer" essay – or what they think is the ideal answer – without critical analysis. Therefore, the calibration essays need to appear authentic and include common misconceptions, misunderstandings, and spelling and grammatical errors that are encountered in a real class.

Next, the author generates style and content questions (called calibration questions) that serve as reviewer guidelines and address the essential points the instructor wants students to learn. The calibration questions can have a variety of formats, including multiple-choice, yes/no, or none/some/many. The style questions address writing style, e.g., "Is the essay grammatically correct?" and "Are there spelling errors in the text?" The content questions address important points and common areas of student misunderstanding and focus student attention on key content. The author uses the calibration questions to score the calibration essays and provide feedback so students can improve their reviewing ability before reviewing peer essays.

We created the calibration questions for the "Earthquakes and Plate Boundaries" assignment by adapting the types of questions in existing chemistry assignments that had been optimized over several years. Box 2 shows the calibration questions in the CPR format. This type of assignment sets learning science content as the main learning goal, generally the primary concern of most science instructors. Therefore, Earth science content questions outnumber style questions, and the style questions simply address basic writing guidelines, such as inclusion of a topic sentence, grammatical and/or spelling errors, indications of plagiarism, and essay organization. This type of assignment is not constructed with explicit additional learning goals for introductory science students to learn how to write and actively develop their metacognitive understanding of the writing and review process, although they do practice those skills when completing the assignment. Lastly, the specific instructions to students for completing the assignment were refined (Box 1).

CPR ASSIGNMENT STAGES AND SCORING

Instructions on how to use CPR are also available online at http://cpr.molsci.ucla.edu and http://serc.carleton.edu/introgeo/peerreview/cpr.html. Students begin using CPR with a "Tour of CPR" that takes students through a preview and tutorial of the four main stages, i.e., essay submission, calibration, peer review, and self review, of a CPR assignment. After completing the tour, students can then access the actual assignment. In response to the instructions and guidelines, students study the source materials and write an essay that must be submitted to the CPR program by the text entry deadline, which is set by the instructor. After the deadline, CPR will not accept student input without instructor intervention.

Students who meet the text entry deadline are given access to the calibration stage, in which students practice reviewing by answering the calibration questions and scoring the essays on a scale of 1 (poor) to 10 (best). The instructor sets the minimum level of accuracy required of students in the calibration stage before they begin the peer-review stage. Students who fail to meet the minimum requirement are allowed one more attempt to improve their accuracy in reviewing the calibration essays. During this process, CPR calculates for each student a "reviewer competency index" (RCI) from 1 (low) to 6 (high) that is a measure of student reviewing ability and is determined by how accurately the student reviewed the calibration essays based on the instructor's grading scheme.

In the next stage, CPR randomly assigns three student reviewers to each submitted essay, and each student reviews and scores three submitted essays. For each essay, the reviewers answer the calibration questions (Box 2), assign a score from 1 to 10, and write comments to justify the review. In calculating the final essay score using the three peer scores, the score given by a more proficient reviewer, i.e., a student with a higher RCI, is weighted more heavily than the score of a less proficient reviewer. Finally, each student reviews and scores his or her own essay.

Each student's final score for a CPR assignment is based on four components: 1) essay score, as determined by the weighted average of scores given to the student's essay by three peers; 2) calibration proficiency, as determined by accuracy in reviewing and scoring the calibration essays; 3) peer review proficiency, as determined by consistency with fellow reviewers of the three essays reviewed by the student; and 4) self-review proficiency, as determined by consistency with the three reviewers of the student's essay. The instructor chooses a grading scheme for each component (essay, calibration, peer review, and self-review), the component's percent contribution to the final assignment score, and the level of required reviewer proficiency in the calibration, peer review, and self-review stages. The program will warn the instructor if an essay has been reviewed by one or more poor reviewers or lacks one or more completed reviews by flagging the essay for instructor review. The instructor also has substantial freedom, such as over-ruling the calculated score, to review essays and assignment scoring. In this study, the instructor reviewed less than 10% of the total number of essays, either in response to a flag by the program or to a student concern. For each assignment, the instructor spent 6-8 hours reviewing essays, answering student questions, and monitoring and resolving implementation issues. The complete process for implementing a CPR assignment (enrolling students into the program, selecting start and end dates for the assignment stages, and choosing a grading scheme) can be completed in under two hours.

RESULTS

To check for differences in baseline student ability between the two sections, t-test analyses were completed by comparing student scores on the diagnostic test and on the average of the first two exams by section (Table 1). The results showed no statistically significant differences between the mean scores, indicating that baseline student ability was equivalent for the two sections.

T-test analyses were conducted using student scores on the third exam from the essay and multiple-choice questions directly related to earthquakes and plate boundaries (Table 2). The results indicated a statistically significant difference between the two sections in performance on the essay question but not on the multiple -choice questions. Students who completed the CPR assignment statistically performed better on the essay question than students who completed the video and essay assignment. The two sections performed statistically the same on the multiple-choice questions.

At the end of the course, the instructor had a teaching assistant conduct a paper survey to obtain student feedback on CPR, and 240 student surveys were collected. Students were asked to rate the value to their learning of seven components of the course, including CPR. On a scale from 1-5, with 1 being least valuable and 5 most valuable, students rated the course notes posted online using WebCT as the most valuable component (4.04) and the lectures as second most valuable (3.17). Students rated CPR assignments as the least valuable with an average score of 1.55, and the textbook as the next least valuable (1.97). The quizzes (2.64), non-CPR homework assignments (2.61), and in-class assignments (2.66) were rated in the middle. Also, the students reported that they spent just over 2 hours completing a CPR assignment.

Students were asked to identify at least one aspect of the CPR assignments that they found useful. Almost 36% (86/240) of students indicated that doing the CPR assignment helped them to learn the material. Nearly 20% (47/240) said writing was the main reason for their learning: "You had to write about what you read and perhaps previously know. This is useful because it connects with meaningful learning and checks comprehension" and "Writing essays did force me to learn more/make connections between the things I was learning." Close to 18% (44/240) said reviewing was the main reason: "CPR assignments helped me understand the material, because I learned from peer reviews and self assessment" and "The peer review, because you could see how well you covered needed information and get feedback by those who did the same assignment." Of note, nearly 20% (47/240) specifically answered this question by saying there were no aspects of CPR they found useful: "I did not find any aspects of the CPR assignments useful" and "There is nothing useful with the CPR assignments. I feel that they were a waste of time and did not teach me anything about Geology. They would be better used with an English class."

Students were also asked to identify at least one aspect of the CPR assignments that they would like to see improved. Many students (43%, 104/240) felt the peer review process was unfair: "I think it (the grading) is incredibly inaccurate and unfair" and "I think it is unfair that we are graded by other classmates and by how well we grade others, and whether or not our answers were the same." The second most common suggestion (15%, 37/240) was to change or increase clarity in the grading criteria: "The grading and level of difficulty and strictness of answers" and "If you have to keep it, clearer criteria on evaluation, [it] was difficult to do peer reviews because criteria and essays were not clear." Other types of suggestions were far fewer in number.

TABLE 1. T-TEST ANALYSES OF BASELINE STUDENT ABILITY IN THE COURSE

Section	n cases analyzed	Diagnostic test score (s.d.)	Average of prior exams (s.d.)
1	150	69.3 (13.2)	72.5 (11.7)
2	153	67.1 (14.3)	73.6 (13.1)
t-value		1.375	-0.753
p-value[1]		0.17	0.452

[1]2-sided p-values reported. $p < 0.05$ considered statistically significant.

TABLE 2. T-TEST ANALYSES OF STUDENT PERFORMANCE ON THIRD EXAM ASSESMENTS

Section	n cases analyzed	Essay Score (s.d.)	Multiple-choice score (s.d.)
1	150	2.10 (0.96)	4.72 (1.70)
2	133	1.75 (0.99)	4.47 (1.69)
t-value		3.086	1.282
p-value[1]		0.002	0.201

[1]2-sided p-values reported. $p < 0.05$ considered statistically significant.

DISCUSSION

Utilizing web-based management, CPR enabled the inclusion of three detailed writing assignments in a large enrollment, introductory geology course without overburdening the instructor. Hundreds of CPR assignments, including the ones developed by the authors of this study, are available for use by instructors wishing to implement more frequent and in-depth writing assignments. For each CPR assignment in this study, students studied web-based and paper resources, wrote an essay, and reviewed seven essays (three instructor, three peer, and their own) on the topic. Comparing instruction on earthquakes and plate boundaries using a CPR assignment vs. an instructional video lecture and homework essay with extensive instructor feedback, students mastered more content via CPR instruction.

Although some students recognized the learning potential of completing CPR assignments, many expressed concern, particularly about the peer review process. A possible reason for this response was that this study was

conducted in 2002, when web-based instruction was extremely new for nearly all the students enrolled in the course. Students are known to resist new technology and teaching styles that are not consistent with their past experiences (Shaw and Marlow, 1999), and the students in this study likely reacted negatively because of our early implementation of CPR. Since then CPR has become more widespread, however, CPR as an instructional approach still requires careful implementation, such as giving sufficient time for students to become acclimatized to this new approach (Robinson, 2001), explaining how CPR works and the potential benefit to students (Walvoord et al., 2008), and selection of appropriate assignments (Reynolds and Moskovitz, 2008). As Walvoord and colleagues reported, by clearly introducing CPR and having a positive instructor attitude, they found only 10% of their students stated concerns about the peer review process. The instructor can reassure students that students do have the ability to evaluate peers and that the instructor has the ability and the will to intercede if students feel that their writing was not appropriately reviewed by their peers.

In practice, scientists must not only write papers, proposals, and reports, but they must evaluate peer writing in scientific papers and research proposals as a prominent aspect of their profession. This study indicates that CPR can help instructors overcome the daunting logistic challenge of incorporating in-depth writing assignments in large, introductory science courses to develop content understanding and provide early training for large numbers of science students in writing, peer review and self-assessment. Thus, CPR offers geoscience instructors a tool to build the professional skills of future scientists and to address the call in the National Science Education Standards for greater communication and explanation by students in science courses.

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REFERENCES

Akkus, R., Gunel, M., and Hand, B., 2007, Comparing an inquiry-based approach known as the Science Writing Heuristic to traditional science teaching practices: are there differences? International Journal of Science Education, v. 29, p. 1745-1765.

Bank, C. G., 2006, Reading and writing taught in a sophomore course on plate tectonics, Journal of Geoscience Education, v. 54, p. 25-30.

Bereiter, C. and Scardamalia, M., 1987, The Psychology of Written Composition, Hillsdale, NJ, Lawrence Erlbaum Associates, 389 p.

Burke, K. A., Greenbowe, T. J., Lewis, E. L., and Peace, G. E., 2002, The Multi-Initiative Dissemination Project: Active-learning strategies for college chemistry, Journal of Chemical Education, v. 79, p. 699.

Burke, K. A., Greenbowe, T. J., and Gelder, J. I., 2004, The Multi-Initiative Dissemination Project Workshops: Who Attends Them and How Effective Are They? v. 81, p. 897-902.

Carlson, P. A., and Berry, F. C., 2003, Calibrated Peer Review and assessing learning outcomes, 33rd ASEE/IEEE Frontiers in Education Conference, Boulder, CO.

Cervato, C., Rudd, J., and Ridky, R., 2003, Calibrated Peer Review for the Earth Sciences: a prototype assignment on earthquakes and plate tectonics. Abstracts with Programs (Geological Society of America), v. 35, n. 6, p. A-441.

Cervato, C., Rudd, J. A. II, and Wang, V. Z., 2007, Diagnostic testing of introductory geology students, Journal of Geoscience Education, v. 55, p. 357-363.

Eikey, R., 2003, Significant Figures – Just the Basics, CPR Assignment, Molecular Science Edited Library, http://cpr.molsci.ucla.edu/preview_public.asp?a_id=700030&e=e (accessed 6/1/2009).

Gerdeman, R. D., Russell, A. A., and Worden, K. J., 2007, Web-based student writing and reviewing in a large biology lecture course, Journal of College Science Teaching, v. 36, p. 46-52.

Halliday, M. A. K., and Martin, J. R., 1993, Writing Science: Literacy and Discursive Power, Pittsburgh, PA, University of Pittsburgh Press, 304 p.

Hanrahan, M., 1999, Rethinking science literacy: enhancing communication and participation in school science through affirmational dialogue journal writing, Journal of Research in Science Teaching, v. 36, p. 699-718.

Heise, E. A., Palmer-Julson, A., and Su, T. M., 2002, Calibrated Peer Review writing assignments for introductory geology courses, Abstracts with Programs (Geological Society of America), v. 34 (6), A-345.

Hohenshell, L. M., and Hand, B., 2006, Writing-to-learn strategies in secondary school cell biology: a mixed method study, International Journal of Science Education, v. 28, p. 261-289.

Holliday, W. G., Yore, L. D., and Alvermann, D. E., 1994, The reading-science learning-writing connection: breakthroughs, barriers, and promises, Journal of Research in Science Teaching, v. 31, p. 877-893.

Journal of Geological Education, 1991, v. 39, p. 173-422.

Kelly, G. J., and Chen, C., 1999, The sound of music: construction science as scoiocultural practices through oral and written discourse, Journal of Research in Science Teaching, v. 36, 883-915.

Keys, C. W., 1999, Revitalizing instruction in scientific genres: connecting knowledge production with writing to learn in science, Science Education, v. 36, p. 1065-1084.

Leydens, J. A., and Santi, P., 2006, Optimizing faculty use of writing as a learning tool in geoscience education, Journal of Geoscience Education, v. 54, p. 491-502.

Mango, H. N., 2000, A reading and writing approach to teaching environmental geology, Journal of Geoscience Education, v. 48, p. 662-666.

Margerum, L.D., Gulsrud, M., Manlapez, R., Rebong, R., and Love, A., 2007, Application of Calibrated Peer Review (CPR) writing assignments to enhance experiments with an environmental chemistry focus, Journal of Chemical Education, v. 84, p. 292-295.

Moore, R., 1993, Does writing about science improve learning about science? Journal of College Science Teaching, v. 22, p. 212-217.

National Research Council, 1996, National Science Education Standards, Washington, DC, National Academy Press, 272 p.

Peck, W. H., 2004, Teaching metastability in petrology using a guided reading from the primary literature, Journal of Geoscience Education, v. 52, p. 284-288.

Pelaez, N. J., 2002, Problem-based writing with peer review improves academic performance in physiology, Advances in Physiology Education, v. 26, p. 174-184.
Peters, E. K., 1996, Writing across the curriculum meets introductory geology, Journal of Geoscience Education, v. 44, p. 65-67.
Peterson, C. D., Anderson, L. L., and Michtom, W. D., 1996, Applications of undergraduate research proposals in general-education earth-science courses, Journal of Geoscience Education, v. 44, p. 197-201.
Plutsky, S. and Wilson, B.A., 2004, Comparison of three methods for teaching and evaluating writing: A quasi-experimental study, Delta Pi Epsilon Journal, v. 46, p. 50-61.
Prain, V., 2006, Learning from writing in secondary science: some theoretical and practical implications, International Journal of Science Education, v. 28, p. 179-201.
Prichard, J.R., 2005, Writing to learn: An evaluation of the Calibrated Peer Review™ program in two neuroscience courses, Journal of Undergraduate Neuroscience Education, v. 4, p. A34-A39.
Prothero, W. A. and Kelly, G .J., 2008, Earth data, peer review, and peer review in a large general education oceanography class, Journal of Geoscience Education, v. 56, p. 61-72.
Rankey, E. C., 2003, The use of critical thinking skills for teaching evolution in an introductory historical geology course, Journal of Geoscience Education, v. 51, p. 304-308.
Reynolds, J. R. and Moskovitz, C., 2008, Calibrated Peer Review assignments in science courses: are they designed to promote critical thinking and writing skills? Journal of College Science Teaching, v. 37, p. 60-66.
Rivard, L. P., 1994, A review of writing to learn in science: implications for practice and research, Journal of Research in Science Teaching, v. 31, p. 969-983.
Robinson, R., 2001, An application to increase student reading and writing skills, American Biology Teacher, v. 63, p. 474-480.
Rudd, J. A., II, Greenbowe, T. J., and Hand, B., 2007, Using the Science Writing Heuristic to improve students' understanding of general equilibrium, Journal of Chemical Education, v. 84, p. 2007-2011.
Russell, A., 1997, Journal of Chemical Education, Symposium on systemic reform in chemistry, v. 74, p. 1268.
Russell, A. A., Chapman, O. L., and Wegner, P. A., 1998, Molecular Science: Network-deliverable curricula, Journal of Chemical Education, v. 75, p. 578-579.
Russell, J. and Pearson, M., 2004, Instructional technology jewels, Journal of College Science Teaching, v. 33, p. 24-28.
Shaw, G. and Marlow, N., 1999, The role of student learning styles, gender, attitudes and perceptions on information and communication technology assisted learning, Computers and Education, v. 33, 223-234.
Shrout, P. E. and Fleiss, J .L., 1979, Intraclass Correlations: Uses in Assessing Rater Reliability, Psychological Bulletin, v. 2, p. 420-428.
Stokstad, E., 2001, Reintroducing the intro course: Reading, writing, and chemistry are potent mix, Science, v. 293, p. 1610.
Takao, A. Y., Prothero, W. A., and Kelly, G. J., 2002, Applying argumentation analysis to assess the quality of university oceanography students' scientific writing, Journal of Geoscience Education, v. 50, p. 40-48.
Walvoord, M. E., Hoefnagels, M. H., Gaffin, D. D., Chumchal, M. M., and Long, D. A., 2008, An analysis of Calibrated Peer Review (CPR) in a science lecture classroom, Journal of College Science Teaching, v. 37, p. 66-73.
Wells, N. A., 1997, Class journals, grading writing, and teaching writing style, Journal of Geoscience Education, v. 45, p. 314-316.
Yore, L. D., 2003, Examining the literacy component of science literacy: 25 years of language arts and science research, International Journal of Science Education, v. 25, p. 689-725.

APPENDIX:

BOX 1. CPR ASSIGNMENT INSTRUCTIONS

Assignment goals:

1. Understand the importance of earthquakes in the development of plate tectonic theory
2. Write an essay in which you relate earthquakes and their characteristics to the different types of plate boundaries

Source material:

1. World seismicity map (http://www.neic.cr.usgs.gov/neis/general/seismicity/world.html
2. Earthquakes and plate tectonics (http://vulcan.wr.usgs.gov.Glossary/Seismicity/what_causes_earthquakes.html)
3. Earthquakes and stress (http://earthquake.usgs.gov/image_glossary/earthquake.html)
4. Earthquakes and "stick-slip" (http://earthquake.usgs.gov/image_glossary/stickslip.html)
5. Plate tectonics and plate motions (http://pubs.usgs.gov.publications/text/understanding.html)

Student instructions:

1. If relevant, review your class notes and course textbook.
2. Study the world seismicity map, and consider how the distribution of earthquakes supports the theory of plate tectonics.
3. Skim the three resources on "Earthquakes" to develop a brief description of the process that leads to an earthquake.
4. Skim the resource "Earthquakes and plate tectonics", study the resource "Plate tectonics and plate motions", and analyze the earthquake depths on the world seismicity map to develop a discussion of the three major types of plate boundaries. When analyzing the world seismicity map, carefully study the arc of earthquakes along the northern and western Pacific Ocean and the arc along the western coast of South America. Note the progression of earthquake depth at each arc, and hypothesize what these data suggest is occurring at this specific type of plate boundary. Note that the depth scale has units of kilometers (km).
5. In discussing plate boundaries, focus on plate motions and earthquake depths, not volcanic activity.

Guiding questions:

In your studies of the source material and the drafting of your essay, consider the points raised by the following questions:

1. Where do most earthquakes occur across the globe, and how does the data support the theory of plate tectonics?
2. What happens when an earthquake occurs at a plate boundary?
3. What general type of movement and earthquake depths characterize the different plate boundaries?
4. What are some example locations for the different types of plate boundaries?
5. Why is there a progression in the depths of earthquakes found in certain regions of the world, such as the western coast of South America, and why do the deepest earthquakes occur in these regions?
6. Why can convergent boundaries be found at very different geographic locations, for example, mountain belts like the Himalayas and ocean trenches like the Marianas Trench?

Writing prompt:

Write an essay of 275-425 words in which you relate earthquakes to plate boundaries. Be sure that you address the Guiding Questions in your essay, but remember that you are writing an essay that integrates ideas and information. In other words, do not simply provide a list of answers to the Guiding Questions.

BOX 2. CALIBRATION AND PEER REVIEW QUESTIONS

1. Does the first sentence introduce the subject of the entire essay (does the essay have a descriptive topic sentence)?
2. Does the essay indicate that the distribution of earthquakes supports the theory of plate tectonics (the existence of crustal plates and the movement of these plates) because most earthquakes occur along the boundaries of crustal plates (along plate boundaries)?
3. Does the essay indicate that a sudden or abrupt movement along a plate boundary causes an earthquake?
4. Does the essay identify the three major types of plate boundaries (divergent, convergent and transform boundaries)?
5. For the case of a divergent boundary, does the essay provide details of (1) type of movement (plates spread away from each other), (2) example location (for example, mid-ocean ridges), and (3) common earthquake depths (33 km or less)?
6. For the case of a convergent boundary, does the essay provide details of (1) type of movement (plates come together or collide with each other), (2) example location (for example, the Japan Trench, or another trench location in the Ring of Fire), and (3) common earthquake depths (ranging from less than 33 km up to 800 km)?
7. Does the essay indicate that the deepest earthquakes occur where an oceanic plate is undergoing subduction (being forced downward)?
8. Does the essay indicate that different convergent boundaries can have different types of plate collisions, such as oceanic-continental, continental-continental, and oceanic-oceanic plate collisions? (including at least 2 different types of collisions is sufficient)
9. For the case of a transform boundary, does the essay provide details of (1) type of movement (plates slide past each other), (2) example location (for example, the San Andreas Fault), and (3) common earthquake depths (33 km or less)?
10. Does the essay contain errors in grammar that reduce the readability of the essay (e.g., run-on sentences, sentence fragments, missing articles, subject-verb disagreements, etc.) and/or any errors in spelling?
11. Does the essay include easily identifiable instances of plagiarism, i.e., a sentence or more taken intact or nearly intact from another source?
12. Does the text or sections of the text read like a list of answers to the guiding questions (like a series of stated answers as opposed to an organized essay in which ideas are related to each other)?
13. How would you rate this text?