# Implementation of Peer-Reviewed Homework Assignments

**By Richard N. Zare, Charles T. Cox, Jr., Katherine Murphy, and Camille Bayas**

*In large, introductory courses, instructors and teaching assistants often struggle to provide detailed feedback on student homework in a timely manner. Here we describe a peer-reviewed homework system that provides quick turnaround while offering flexibility in the construction of homework problems. Homework is administered through a cycle, which always consists of weekly peer-reviewed feedback on paper-based homework. The peer-review component has two purposes: (a) it provides students completing homework with detailed explanations of the correctness of their approach, and (b) it provides peer reviewers an opportunity to review other problem-solving strategies. By examining other students' strategies, peer reviewers gain greater insight into problem solving. We have tested this approach in a general chemistry class at a large institution and observed benefits for students and instructors. This article discusses peer-reviewed homework design and implementation, as well as the results obtained in a large-enrollment class.*

Problem-solving is an important skill that students gain in the science classroom (Gabel & Bunce, 1994). Homework is one of the primary tools that provide students the framework to practice and improve both critical thinking and problem-solving skills (Cuadros, Yaron, & Leinhardt, 2007; Fyneweaver, 2008; Hahn & Polik, 2004). An array of platforms have been developed and disseminated for the delivery of homework assignments, which include both paper-based and online (McGraw-Hill Connect, www.mheducation.com; WebAssign, https://www.webassign.net/login.html; Mastering Chemistry, http://www.pearsonmylabandmastering.com/northamerica/masteringchemistry/; OWL, http://www.cengage.com/owl/; and SmartWork) paradigms. Research has supported that paper-based and online homework provides comparable advantages with respect to gains in performance (Eichler & Peeples, 2013; Richards-Babbs, Drelick , Henry, & Robertson-Honecker, 2011). A problem with both platforms, however, is instructor ability to provide detailed feedback to students regarding problem-solving strategies beyond whether an answer is right or wrong in a timely manner. Although many online homework methods provide immediate feedback, this platform does not allow for analysis of the students' critical thinking and problem-solving methods, and is often limited in the types of problems that can be asked.

The goal of this article is to expand on the frameworks for homework by discussing the incorporation of student peer review to provide timely feedback and assessment. The peer-review aspect can be incorporated with either the online or paper-based approaches, but this article emphasizes the incorporation with paper-based assignments. The feedback provided from peer review can be done with a rapid turnaround. Furthermore, students are given detailed feedback, which is important for refinement and promotion of problem-solving abilities (Hattie, 2008; Marzano, Pickering, & Pollock, 2001).

The peer-review component was incorporated to provide opportunities for refining problem-solving skills, given that research has shown that peer review has been attributed to increased student performance and confidence (Berry & Fawkes, 2010; Ertmer et al., 2010; Mulder, Pearce, & Baik, 2014; Walvoord, Hoefnagels, Gaffin, Chumchal, & Long, 2008). Furthermore, Calibrated Peer Review (CPR) assignments (http://cpr.molsci.ucla.edu/Home.aspx) have been widely implemented successfully across chemistry and other science curricula to allow for the incorporation and assessment of writing assignments. CPR assignments couple case-based scenarios with writing assignments that are later peer reviewed. The calibration phase uses assignments of known quality to calibrate the peer reviewers and ensure reliable reviews. The robust nature of the CPR website allows for implementation of writing assignments with feedback in large-enrollment classes. Homework assignments, by analogy, designed using an open-ended approach with longer problem-solving activities or more in-depth qualitative discussions, provide an excellent framework for peer review. Moreover, peer-reviewed grading permits an active learning process for the reviewers, as they learn a greater variety of problem-solving strategies by correcting their peers' work.

The peer-review homework was incorporated into a course that was cotaught by two instructors (a lecturer and a full professor) with the assistance of a head teaching assistant (TA) who was responsible for the core administrative responsibilities. The head TAs (who are coauthors) developed the model for submitting homework and helped oversee and facilitate the process. The course is designed to be an advanced freshman general chemistry course for students who have already completed AP chemistry (or a comparable course) successfully. The focus of the course is to provide a deeper treatment of each of the topics with a calculus-based approach. Students who do not have the prerequisite requirement of a "5" on the AP chemistry exam can only enroll in the course by passing a placement test. Furthermore, students taking the course should be eligible to enroll in the third quarter of calculus. The population of the course is quite diverse, consisting of domestic and international students with an approximately equal number of male and female students. Students are generally majoring in a STEM (science, technology, engineering, and mathematics) field, with engineering and premed being the two most common focuses.

Two years of anonymous student feedback via formal course evaluations, as well as instructor and TA discussions, have supported the conclusion that all users favor the peer-review homework system over previously used, traditional homework systems. Furthermore, the evaluations showed that students believed they gained greater insight with the peer-review process than without it. This article outlines how the homework was implemented and includes some data and a discussion of student responses.

## Homework format

Each homework assignment was designed to take approximately 3–4 hours to complete and included 6–10 problems consisting of lecture and laboratory items pertinent for preparing for the hour-long exams. There were two hour-long midterms in the 10-week course and one 3-hour-long final exam. The homework problems focused on exercises and longer extended problems that used both quantitative strategies and written descriptions. Students were encouraged to work together in small groups. Sample homework items are provided in Scheme 1 shown in the Appendix.

The cycle in Figure 1 illustrates the peer-grading approach. This cycle was repeated each week for 9 of the 10 weeks of the academic quarter. Students would pick up a new, blank homework assignment during their laboratory section, which was on Wednesday, Thursday, or Friday. The homework was due 1 week later to the laboratory TA. The head TA then randomly sorted the homework into separate folders. The peer reviewers were given a 3-hour window to pick up assignments on Friday afternoon. The homework assignments were peer reviewed by the students over the weekend and returned to the TAs on Monday. Once returned, the TAs would review the assignments

**FIGURE 1**

**The peer-grading homework cycle.**

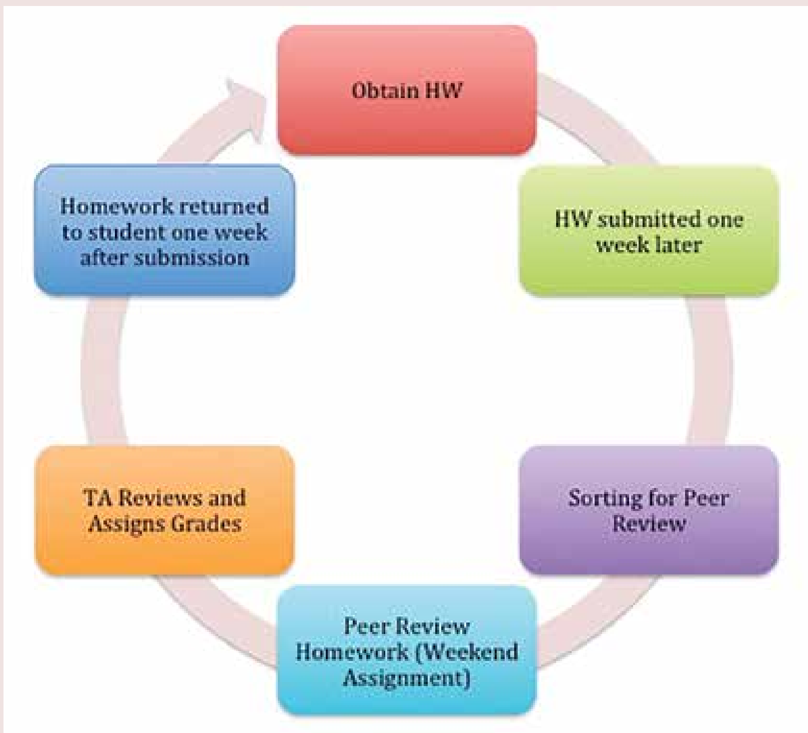


**TABLE 1**

**The peer-grading check in/out form.**

| Name | Student number | Key number | Check out (initials) | Check in (initials) | Homework numbers |
|---|---|---|---|---|---|
| Smith, John | 47 | 1 | | | |
| Smith, John | 37 | 2 | | | |
| Smith, John | 46 | 3 | | | |
| Smith, John | 21 | 4 | | | |
| Smith, John | 24 | 5 | | | |
| Smith, John | 19 | 6 | | | |
| Smith, John | 40 | 7 | | | |
| Smith, John | 49 | 8 | | | |
| Smith, John | 41 | 9 | | | |
| Smith, John | 11 | 10 | | | |

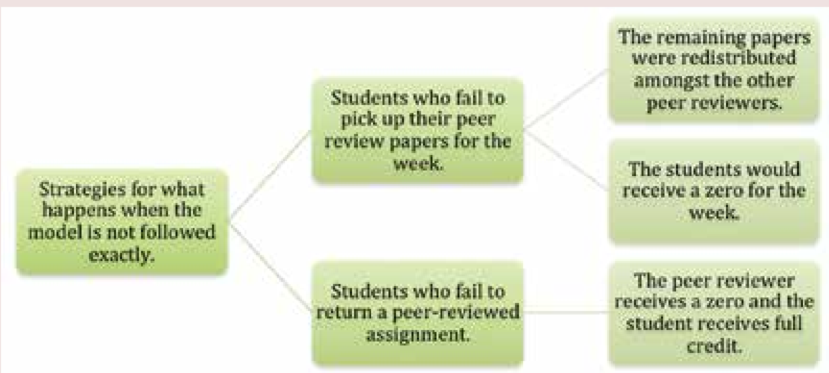
briefly to ensure reviewer consistency and reliability. After reviewing the comments and quality of the assignments, TAs would assign a numerical grade to the student who completed the individual homework and to the reviewer for the peer review. Overtly negative comments yielded an automatic score of "0" for the reviewer. Having the teaching assistants assign grades in lieu of the peer reviewers ensured consistency with the final grades and eliminated issues students may have with having grades assigned by their peers. TAs then returned the homework in laboratory section, exactly 1 week after the assignment was submitted.

## *Organizing the peer-grading model*

At the start of the quarter, students were given a randomized homework number to use as identification for all homework and peer-reviewing activities. By not using names or student ID numbers, both the student and the peer reviewer maintained anonymity and therefore fairness in reviewing. When peer reviewers picked up their assignments to review, they signed out the assignments and answer key number on a sign in/out sheet and signed them in again the following Monday. This process ensured that students did not take their own homework to review and that all assignments were accounted for. In the case of a student losing a homework assignment during grading, or claiming to have received homework when they did not (i.e., a student turning a homework in late directly to the peer reviewer), the record ensured that students were held accountable for the assignments they were reviewing. Table 1 provides an example of the peer grading check-in and check-out form. Each week, approximately 20 students in a 150-student class would peer review. Each student reviewed only 7–10 homework assignments and only had to review twice during the quarter. The schedule for reviewing assignments was completed at the start of the quarter and published; therefore, students could plan when they would have the extra responsibility of reviewing. Figure 2 illustrates the policies adopted for students who failed to follow the model exactly. Surprisingly, the issue of a student losing or failing to return papers they peer reviewed never arose in the final implementation of this method.

**FIGURE 2**

**Policies adopted for students who did not follow the model exactly.**

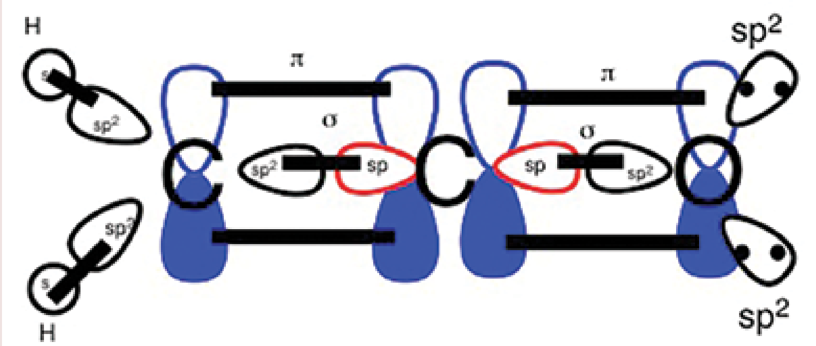



## *Expectations of students (peer reviewing)*

Every student, including the peer reviewers, would be required to submit a homework assignment each week during lab. A portion of the laboratory time each week is allotted for working on homework problems; therefore, the assignments are made available during lab and collected a week later in lab. All students are given the same amount of time to complete the homework assignments using this approach. On Friday, the peer reviewers would collect the assignments during lecture or by 3 p.m. (at the end of office hours) and would review them and return them to the head TA on the following Monday during lecture. The answer key was provided and students were instructed to review each problem carefully, making note of any errors in strategy. The answer key was written such that students who are familiar with the material should understand the description; however, each problem did not have extensive information regarding how to provide feedback. During the first lecture, we described what peer reviewers needed to do in terms of feedback; specifically, we pointed out that reviewers should note errors and provide comments as needed. More computational problems tended to provide greater opportunities for giving feedback. The answer (as provided for students) for Problem 3 in Scheme 1 (in the appendix) is shown in Figure 3. In part, the answer key is limited to again measure students' understanding of the concepts, as well as provide some flexibility with regard to the type of feedback provided. We wanted to avoid being too algorithmic.

**FIGURE 3**

**The answer key for the bonding model for Ketene (Problem 3 in Scheme 1, shown in the Appendix). Feedback should have emphasized whether the correct types of hybrid orbitals were identified, the correct types of bonds were identified, and the correct orientation of the orbitals. Students were told that the two $\pi$ bonds are orthogonal.**




### *TA assessment of homework and peer review*

In previous years of this course, when TAs reviewed each homework assignment thoroughly and provided detailed comments, each TA spent upwards of 6–8 hours per week reviewing and grading homework assignments. This led instructors to write questions that facilitated less time for reviewing. With this new method, each TA spent an average of 2 hours per week grading the peer-reviewed homework, and the questions asked of students could be longer, more qualitative, and more in depth because they no longer needed to be designed for ease of grading. Every week, each TA would spend approximately 2 hours once the peer-reviewed homework was returned reviewing feedback, checking consistency, and assigning grades. The assignment of grades was designated specifically to the TAs to eliminate any perceived conflict with students' grading by other students. Given the smaller time commitment for TAs, this model would be ideal for large classes with limited instructional or TA support.

### *Assessment of the homework and peer-grading assignments*

The homework assignments and peer-review responsibilities contributed approximately 10% to the final course grades. Each homework assignment was graded out of 3 possible points with full credit generally being awarded for 80% correct and above, a 2 being awarded for 60% correct but less than 80%, and a 1 awarded for a completed assignment that has less than 60% correct. The 80% and 60% breaks are used in other courses in the department, which also follow similar grading criteria for homework. The peer-review assignment was graded on a scale of 0–6. If the paper contained comments and was graded correctly, the student would earn a 6. Grades less than 6 arose when careless peer-grading errors were observed, feedback was not provided if appropriate, or parts of the assignment were not reviewed.

## Results and discussion

The peer-reviewed homework assignment format was implemented for 4 years in the advanced general chemistry course. The first year, we attempted to assign homework three times a week, which proved to be difficult because we had a high frequency of students who would forget to collect their homework assignments or return them. The workload also proved to be substantial for the teaching assistants with respect to collecting, sorting, and reviewing the homework. We did not collect assessment information during this year, given that it was the first time this scheme was implemented and the instructional staff members were new to the course.

During the second, third, and fourth implementation of the approach, we assigned homework once per week, which proved to be manageable and effective. Students were required to peer review twice during the quarter, and the schedule was set before the first day of class. Each week the entire class was e-mailed a reminder not to forget to pick up the peer grading if applicable. By assigning fewer homework assignments, we expanded the length of the homework to include 8–10 problems each week in lieu of or one or two problems when homework was assigned three times weekly.

Data from fall quarter 2015 supports that students did show sizable improvements from the peer-review activities. A comparison of student exam data for the two midterm exams during the 2015 quarter is shown in Figures 4 and 5. Student results were analyzed in two groups: those who had peer reviewed before the first exam (control) and those who had not peer reviewed before the first exam (treatment). Because all students had peer reviewed prior to the second exam, the group of students who had not peer reviewed before the first exam were considered "treated" by the peer-review process. Using the class data for the first exam, we analyzed whether a statistical difference ($F_{calc}$ = 6.33, 1, 182, 0.012) emerged between the variable group (who did not peer review) and the control group (who did peer review). This difference was not observed on the second hour-long midterm exam ($F_{calc}$ = 9.44 x $10^{-6}$, 1, 179, 0.998) after all students had completed peer grading at least once. This data does support a correlation with peer grading and student success; however, additional research is needed to increase the validity of the research. For the second hour-long midterm exam given during Week 9, all students had opportunities to peer review at least once or twice before the exam. Only 20 students needed to peer review during the last week of the quarter (Week 10). Therefore, the lack of statistical difference observed in the control and variable is not surprising, given that treatment had been applied to both groups at that point. Furthermore, there was not a statistical difference observed in the final exam for 2015 between the control and variable groups ($F_{calc}$ = 0.0132, 1, 180, 0.91), after which both the variable and control groups had

**FIGURE 4**

**A comparison of student score for those who completed (*N* = 140, mean = 86.07) and did not complete (*N* = 45, mean = 79.80) peer grading (peer review) before the first hour-long midterm exam in 2015. Note that the score is out of 105 possible points.**

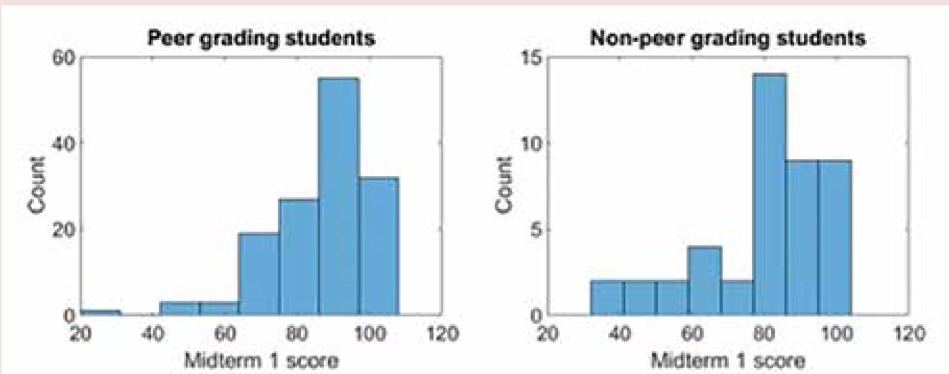
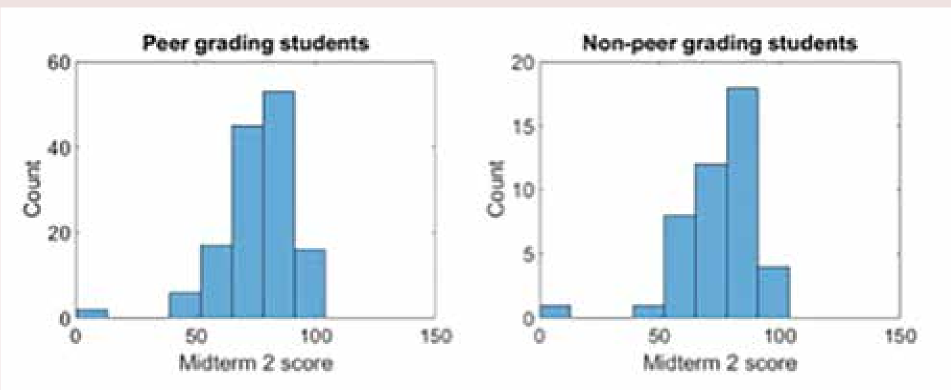



**FIGURE 5**

**A comparison of the hourly exam scores for the same students in the two respective cohorts for the second hour-long midterm exam in 2015 peer review (peer grading); students' mean = 75.68, nonpeer review (peer grading) students' mean = 74.49. The score is out of 100 possible points.**



peer reviewed the same number of times. The courses were smaller in 2013 and 2014, which unfortunately did not provide a reasonable sample size for the respective control and variable groups; therefore, these data were not compared during those academic years.

Surveys, course evaluations, and one-on-one discussions with students helped provide deeper insight into the mechanisms that promote the success of the peer-review approach. Students who received higher grades in the course noted that by reviewing other individuals' papers, they were able to identify common mistakes and gain a greater understanding of how to solve problems and how different chemistry concepts relate to each other. Students had to work diligently to provide constructive feedback that other students could follow and understand. Students who received lower grades in the course noted that peer review conversely provided support by illustrating the problem-solving pathways for problems that they found challenging by providing more textbook-type examples. Some of these students noted that the peer approach made them feel confident by forcing them to probe and rationalize strategies during peer review. These mechanisms for success will be researched in more detail using reflection activities in the next installment of the course. The reflections will be designed to have students collect and analyze thought processes during and after grading. Student feedback showed that a common complaint was attributed to the difficulty of collecting and returning the assignments—especially given the small 3-hour window available for collecting the homework assignments each week. Other options have been considered including the use of course platforms to digitally deliver both homework and peer-review feedback.

Future directions of the project include expanding peer-review activities to organic chemistry courses in the summer, as well as possible explorations with the use of online platforms for delivering and reviewing assignments. This approach has been successfully implemented to allow for greater diversity of homework questions, rapid turnaround, and less time grading for TAs. It has also been shown to provide students with more detailed feedback on their homework, while allowing them insight into other problem-solving strategies when peer reviewing. The exam data and student feedback suggest the peer-reviewed aspect of homework promotes essential problem-solving skills needed for greater success in the course. ■

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## Appendix

### *Scheme 1: Sample homework problems.*

1. Type I diabetics often have to monitor their sugar concentration (glucose, Molecular Weight = 180 g/mol) periodically during the day to determine whether they need sugar or insulin. Scientists have devised a handheld apparatus for instant monitoring of glucose content for quick analysis. These meters provide instant readings using a small (50 microliter) sample with high accuracy and reliability. The primary approach is based on an electrochemical reaction.

The electrochemical reaction is based on the production of $H_2O_2$ catalyzed by an enzyme denoted as $E_o$ for glucose oxidase.

Glucose (aq) + $O_2$ (aq) $\rightarrow$ Gluconic Acid (aq) + $H_2O_2$ (aq) K>>1 (goes to completion)

$H_2O_2$ production can be monitored by a platinum electrode that is highly selective for the half-reaction. The platinum electrode serves as an electron shuttle.

$H_2O_2$ (aq) + 2 $H^+$ (aq) + 2 $e^-$ $\rightarrow$ 2 $H_2O$ $E^o = 1.78$ V

To design a prototype system based on chemistry, you connect the platinum electrode in blood to a standard Cu | $Cu^+$ (1.0 M) with a suitable salt bridge. The pH of blood is buffered at 7.4. Oxygen concentration is static because of the buffering component ($8.0 \times 10^{-3}$ M is the approximate concentration of free oxygen in blood). Biological temperature is 37°C.

$Cu^+$ (aq) + $e^-$ $\rightarrow$ Cu (s) $E^o = +0.520$ V

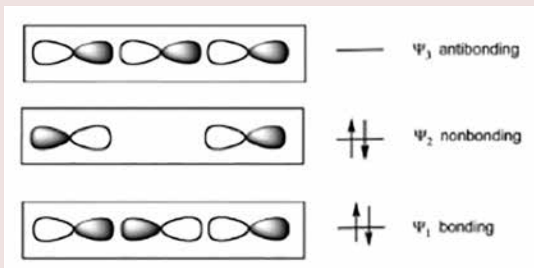
The normal glucose concentration is 75.0 – 120 mg/dl. An individual measures his blood sugar using a 50 microliter sample and receives an electrochemical measure of 0.770 V. Calculate the glucose level in mg/dl. Insulin provides a substitute for the biological catalyst to promote the decomposition of glucose when glucose levels are too high. Should the individual take insulin?

2. Zinc Oxalate $K_{sp} = 2.7 \times 10^{-8}$
Lead Hydroxide $K_{sp} = 1.2 \times 10^{-15}$

Cell 1 Contents: Zn metal and 0.11 M $ZnCl_2$. The cell is mixed with 0.88M $NaHC_2O_4$.
Cell 2 Contents: Pb metal and 0.12 M $Pb(NO_3)_2$. The cell contains 100-mL of 0.50 M $NaNO_2$ to which 0.50 grams of sodium hydroxide is added.
What is the Gibbs free energy for the electrochemical cell?

3. Ketene, $CH_2$=C=O, is an organic molecule that has a single carbon atom doubly bonded to two other atoms. Draw a hybridization bonding model illustrating all hybrid orbitals and the formation of sigma and pi bonds.

4. Here is some electronic structure information about the stable molecule $XeF_2$. In $XeF_2$, the linear F–Xe–F subunit is described by a set of three molecular orbitals (MOs) derived from collinear p-orbitals on each atom. The Xe–F bonds result from the combination of a filled p orbital in the central atom (Xe) with two half-filled p orbitals on the axial atoms (F), resulting in a filled bonding orbital, a filled non-bonding orbital, and an empty antibonding orbital, as shown in figure below, showing the molecular orbitals for $XeF_2$.




This is called a three-center, four-electron bonding scheme. As an aside, it should be mentioned that many textbooks invoke d orbitals to explain this type of bonding, but quantum calculations suggest that the d-orbital participation in the bonding is negligible because of the large energy difference between the filled p orbitals and the empty d orbitals. The three-center-four-electron bonding model has the advantage of dispensing with the need for d orbitals in what are called hypervalent compounds.

A. Calculate the bond order of each Xe-F bond.

B. Draw resonant Lewis dot structures that are consistent with the molecular orbital picture in which the octet rule for F is not broken.

C. Consider the $I_3^-$ molecule, which is known to be stable and linear. Describe its bonding in light of what you have learned about $XeF_2$.

5. Write electron-pushing mechanisms for the following acid-base reactions:

a) $H_2S$ + NaF

b) $NaNH_2$ + $H_2O$

c) HCOOH + NaOH