Appendices for:

Incorporating Concept Development Activities into a Flipped Classroom Structure: Using PhET Simulations to Put a Twist on the Flip

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Appendix 1. Course Syllabus**.**

Chemistry 001 A – Section 060

Fall Quarter 2019

University of California - Riverside

Course Description

Chem 001A is the first course in a three-quarter sequence for General Chemistry. The topics covered include: Chapter 1 – Scientific method and measurement; Chapter 2 – Atomic structure; Chapter 3 – Electronic structure of the atom; Chapters 4 & 5 – Chemical bonding and molecular structure; Chapter 6 & 7 – Compounds and the mole, chemical reactions and stoichiometry; and Chapter 9 – Thermochemistry and Energy of Reactions.

Course Goals

The general goal of Chem 001 A is to begin your training in general chemistry, in particular beginning to ***master the basic concepts and problem solving strategies required in the field of chemistry***, as well as ***gaining a more complete understanding of fundamental concepts*** such as the nature of matter and how interactions between matter result in chemical bonds and reactions. Successfully completing this course will give you the background needed to continue exploring the nature of matter and chemical reactions in Chem 001 B, and will also give you conceptual understanding which will prepare you for organic chemistry (chemistry majors, pre-med students, biochemistry majors) and physical chemistry (chemistry majors).

Student Learning Goals

The specific student learning goals for each chapter are listed on the chapter outlines, and these outlines are available on the Blackboard site.

Course Organization

Chem 001 A has two 80-minute lectures and one 50 minute discussion session each week. You also have one 3-hour lab each week, and the lecture and laboratory portions of the course are coordinated as much as possible. The lab counts as a separate grade, and will not be considered in your lecture grade. Any questions about the lab course should be directed to Dr. Kevin Simpson.

Your weekly discussion group session will be facilitated by a graduate student TA. You will review some of the important skills/concepts from lecture.

Required Materials

•Textbook: OpenStax Atoms First General Chemistry (free, open access textbook)
•In-class response polling; PollEverywhere (using smart phone, tablet, or laptop)
•Scientific calculator (non-graphing/non-programmable)
•Blackboard/iLearn Class Site

Tentative Course Schedule (Textbook reading sections are given for the OpenStax Atoms First General Chemistry textbook; schedule subject to change)

Week 0 and Week 1	Review of measurement conversions (1.4-1.6) – **Flipped Module In-class worksheet on dimensional analysis**
	Atomic structure (2.1-2.3) **– Nuclear atom Concept Development activity**
	Atomic structure and the periodic table (2.3, 2.5) – **Coulomb's law Concept Development activity**
Week 2	Electronic structure of the atom (3.1-3.2) - **Flipped Module clicker activity on de Broglie reading**
	Quantum model of the atom (3.3)
Week 3	Electron configurations (3.4) – **Flipped Module In-class worksheet (electron configurations and magnet properties)**
	Finish Chapter 3 and Review
Week 4	**Exam 1 (Chapters 1-3) - October 22**
	Chemical Bonding (4.1) – **Atomic interactions Concept Development activity**
Week 5	Bonding – ionic vs. covalent bonds (3.5, 4.1-4.2)
	Lewis structures and formal charge (4.4-4.5) – **Flipped Module In-class Activity – Lewis structures of environmentally relevant molecules.**
Week 6	Molecular Structure (4.6) – **Molecular shape Concept Development activity**
	Hybridization (5.2)
Week 7	**Molecular dipole Concept Development activity**
	Future applications of molecular dipoles; Molecular orbital theory (5.4)
Week 8	**Exam 2 (Chapter 4-5) – November 19**
	The mole, molecular weight, and molar mass (6.1)
Week 9	Chemical reactions and stoichiometry (7.1, 7.3-7.4)
Week 10	**Flipped Module In-class Activity – Stoichiometry and producing liquid coal.**
	Moles and solutions (6.3)
December 11	**Final Exam (Chapters 1-7, 9) (11:30-2:30; Location TBD)**

Grading

Your grade will be broken down into the following categories:

Exam 1	100 points
Exam 2	100 points
Final Exam[1]	400 points
Blackboard/iLearn Quizzes[2]	200 points (max of 220 points possible)
In-class poll questions[3]	200 points (max of 220 points possible)

[1]Note, if you miss Exam 1 or 2 the final exam will act as the makeup exam for the missed midterm exam; if you perform better on the final exam, your score on the final will replace your midterm scores:

400 on final = 100 on midterm

360-399 on final = 90 on midterm

320-359 on final = 80 on midterm

280-319 on final = 70 on midterm

240-279 on final = 60 on midterm

[2]You can earn up to a maximum of 220 points (i.e., you can earn 20 "extra credit" points).

[3]Clicker points will be assigned as following:

90% of clicker points earned = 220 points

80% of clicker points earned = 200 points

70% of clicker points earned = 180 points

60% of clicker points earned = 160 points

50% of clicker points earned = 140 points

40 % of clicker points earned = 120 points

30% of clicker points earned = 100 points

These extra points are included to account for any technical glitches you may encounter with your PollEverywhere poll questions, and to provide a buffer for missed classes and/or days in which you forget your clicker. ***Makeup poll points will not be available under any circumstances.***

Final letter grades will be assigned as shown below:

A	920 points or higher
A-	900-919 points
B+	860-899 points
B	830-859 points
B-	800-829 points
C+	760-799 points
C	700-759 points
C-	600-699 points
D+	560-599 points
D	500-559 points
F	less than 500 points

Publication Note on course workload (this was not included in the student syllabus):

Though some flipped classroom implementations reduce the in-person meetings to ensure student workload is not increased in a way that violates institutional course unit requirements, the flipped classroom structure described here did not change the total time for in-person class meetings. When the flipped classroom structure was originally implemented, the increased workload associated with the new pre-lecture learning modules was offset by eliminating previously required traditional online homework activities. Because the new learning cycle activities only required students to complete five extra credit post-test quizzes outside of class, this did not significantly change the overall course workload and no additional outside-of-class activities were removed in this implementation.

Appendix 2. Structure of concept development activities, flipped modules, and in-class application exercises.

1. Unit conversions and dimensional analysis flipped module

   -Pre-lecture homework (made available to students one week prior to the first day of class): video modules with embedded questions on carrying out unit conversions and dimensional analysis; online quiz due prior to in-class activity.

   -In-class activity: students were instructed to work in collaborative groups of 3-4 students and completed the activity sheet on carrying out metric conversions and using dimensional analysis to carry out multi-step unit conversions; selected problems from activity sheet were assessed using a whole-class clicker/polling system.

2. Nuclear atom concept development activity

   -Students were informed prior to class they would need a device capable of accessing the course management quiz system; prior to starting the activity in class, students were instructed to complete the activity pre-test in the course management site (students worked individually on the pre-test).

   -The students were instructed to work in collaborative groups of 3-4 students, and completed the concept development activity described in the Supplemental Information Appendix 3; the instructor and two graduate student teaching assistants were available to answer student questions during the group work; after determining all students has completed the activity sheet, selected questions from the activity were assessed using a whole-class clicker/polling system; instructor-led discussion was used to provide further explanation of concepts as needed (based on responses to the clicker/polling questions); students were instructed to complete the activity post-test in the course management site by midnight the day of the activity (students were informed to complete the post-test without collaborating with other students, and that the post-test scores would act as extra credit toward the final course grade).

   -The subsequent class meeting was devoted to applying the concepts from the nuclear atom activity to help students learn about average atomic mass and how the elements are organized on the periodic table. This was facilitated using instructor-led discussion and whole-class questioning/think-pair-share using a clicker/polling system.

3. Coulomb's law concept development activity

-Students were informed prior to class they would need a device capable of accessing the course management quiz system and the Coulomb's Law PhET simulator (they were provided the link for the online PhET simulator in advance and instructed to test this on their device); prior to starting the activity in class, students were instructed to complete the activity pre-test in the course management site (students worked individually on the pre-test).

-The students were instructed to work in collaborative groups of 3-4 students, and completed the concept development activity described in the PhET instructor resources site (https://phet.colorado.edu/en/contributions/view/5909; these materials are open access, but instructors must first create a verified account to access them); the instructor and two graduate student teaching assistants were available to answer student questions during the group work; after determining all students has completed the activity sheet, selected questions from the activity were assessed using a whole-class clicker/polling system; instructor-led discussion was used to provide further explanation of concepts as needed (based on responses to the clicker/polling questions); students were instructed to complete the activity post-test in the course management site by midnight the day of the activity (students were informed to complete the post-test without collaborating with other students, and that the post-test scores would act as extra credit toward the final course grade).

-The two subsequent class meetings were devoted to applying the concepts from the Coulomb's law activity to help students learn about the electronic structure of the atom, which progressed from the Bohr model of the atom to the quantum mechanical model of the atom. This progression of learning was facilitated using instructor-led discussion and whole-class questioning/think-pair-share using a clicker/polling system.

4. Electron configurations flipped module (the detailed instructor notes, pre-lecture quiz, and in-class activity worksheet are available at the IonicViper instructor resource site: https://www.ionicviper.org/class-activity/thinking-about-electron-configurations-and-magnetism; these materials are open access, but instructors must first create a verified account to access them).

-Subsequent to the two classes devoted to electronic structure, students completed a flipped module on electronic structure.

-Pre-lecture homework (made available to students four days prior to the in-class activity): video modules with embedded questions on drawing electron configurations of neutral atoms and ions, including both orbital notation and condensed electron configurations; online quiz due prior to in-class activity.

-In-class activity: students were instructed to work in collaborative groups of 3-4 students and completed the activity sheet on determining electron configurations and how magnetic properties of metals is dependent on their electronic structure; selected problems from activity sheet were assessed using a whole-class clicker/polling system.

5. Atomic interactions concept development activity

-This was completed in the first class subsequent to the midterm exam.

-Students were informed prior to class they would need a device capable of accessing the course management quiz system and the Atomic Interactions PhET simulator (they were provided the link for the online PhET simulator in advance and instructed to test this on their device); prior to starting the activity in class, students were instructed to complete the activity pre-test in the course management site (students worked individually on the pre-test).

-The students were instructed to work in collaborative groups of 3-4 students, and completed the concept development activity described in the PhET instructor resources site (https://phet.colorado.edu/en/contributions/view/5860; these materials are open access, but instructors must first create a verified account to access them); the instructor and two graduate student teaching assistants were available to answer student questions during the group work; after determining all students has completed the activity sheet, selected questions from the activity were assessed using a whole-class clicker/polling system; instructor-led discussion was used to provide further explanation of concepts as needed (based on responses to the clicker/polling questions); students were instructed to complete the activity post-test in the course management site by midnight the day of the activity (students were informed to complete the post-test without collaborating with other students, and that the post-test scores would act as extra credit toward the final course grade).

-The subsequent class meeting was devoted to applying the concepts from the atomic interactions activity to help students learn about basic ionic and covalent bonding, and the similarities and differences between these two general types of bonding. This was facilitated using instructor-led discussion and whole-class questioning/think-pair-share using a clicker/polling system.

6. Lewis structures and formal charge flipped module (the detailed instructor notes, pre-lecture quiz, and in-class activity worksheet are available at the IonicViper instructor resource site: https://www.ionicviper.org/class-activity/flipped-class-module-lewis-

structures-industrially-and-environmentally-relevant; these materials are open access, but instructors must first create a verified account to access them).

-Subsequent to the class devoted to chemical bonding, students completed a flipped module on drawing Lewis structures, determining formal charge, and how to use formal charge arguments to determine the most plausible structure for a molecule.

-Pre-lecture homework (made available to students four days prior to the in-class activity): video modules with embedded questions on the rules for drawing Lewis structures for molecular compounds, and how to use formal charge to determine the most plausible structure for a molecule; online quiz due prior to in-class activity.

-In-class activity: students were instructed to work in collaborative groups of 3-4 students and completed the activity sheet on drawing Lewis structures for environmentally relevant molecules; selected problems from activity sheet were assessed using a whole-class clicker/polling system.

7. Molecular shape concept development activity

-This was completed subsequent to the Lewis structures in-class activity.

-Students were informed prior to class they would need a device capable of accessing the course management quiz system and the Molecular Shape PhET simulator (they were provided the link for the online PhET simulator in advance and instructed to test this on their device); prior to starting the activity in class, students were instructed to complete the activity pre-test in the course management site (students worked individually on the pre-test).

-The students were instructed to work in collaborative groups of 3-4 students, and completed the concept development activity described in the PhET instructor resources site (https://phet.colorado.edu/en/contributions/view/5910; these materials are open access, but instructors must first create a verified account to access them); the instructor and two graduate student teaching assistants were available to answer student questions during the group work; after determining all students has completed the activity sheet, selected questions from the activity were assessed using a whole-class clicker/polling system; instructor-led discussion was used to provide further explanation of concepts as needed (based on responses to the clicker/polling questions); students were instructed to complete the activity post-test in the course management site by midnight the day of the activity (students were informed to complete the post-test without collaborating with other students, and that the post-test scores would act as extra credit toward the final course grade).

-The subsequent class meeting was devoted to applying the concepts from the molecular shapes activity to help students learn how different types of s-p hybridization result in different molecular shapes/geometries. This was facilitated using instructor-led discussion and whole-class questioning/think-pair-share using a clicker/polling system.

8. Molecular dipoles concept development activity

-This was completed subsequent to the class discussion on hybridization and molecular shape/geometry.

-Students were informed prior to class they would need a device capable of accessing the course management quiz system and the Molecular Dipoles PhET simulator (they were provided the link for the online PhET simulator in advance and instructed to test this on their device); prior to starting the activity in class, students were instructed to complete the activity pre-test in the course management site (students worked individually on the pre-test).

-The students were instructed to work in collaborative groups of 3-4 students, and completed the concept development activity described in the PhET instructor resources site (https://phet.colorado.edu/en/contributions/view/5911; these materials are open access, but instructors must first create a verified account to access them); the instructor and two graduate student teaching assistants were available to answer student questions during the group work; after determining all students has completed the activity sheet; selected questions from the activity were assessed using a whole-class clicker/polling system; instructor-led discussion was used to provide further explanation of concepts as needed (based on responses to the clicker/polling questions); students were instructed to complete the activity post-test in the course management site by midnight the day of the activity (students were informed to complete the post-test without collaborating with other students, and that the post-test scores would act as extra credit toward the final course grade).

-The subsequent class meeting was devoted to applying the concepts from the molecular dipoles activity to future topics that were to be covered in the next course in the general chemistry sequence (students were introduced to the concept of intermolecular forces and why intermolecular forces are important in understanding macroscale properties of molecules; students were informed this concept would be covered in the next general chemistry course). This was facilitated using instructor-led discussion and whole-class questioning/think-pair-share using a clicker/polling system.

9. Stoichiometry flipped module (the detailed instructor notes, pre-lecture quiz, and in-class activity worksheet are available at the IonicViper instructor resource site: https://www.ionicviper.org/class-activity/stoichiometric-calculations-general-chemistry-

flipped-classroom-module; these materials are open access, but instructors must first create a verified account to access them).

-After the second midterm exam, students engaged in two class meetings devoted to introducing the concept of the mole and how the mole unit is used to represent the whole number ratios of atoms/molecules in chemical reactions on a macro-scale. Though these classes did not use formal concept development activities, whole-class questioning with polling and think-pair-share discussion was used to guide the students in a way that modeled the exploration and concept development phases of the learning cycle. Subsequent to these two classes, a flipped module on carrying out stoichiometric calculations was employed.

-Pre-lecture homework (made available to students four days prior to the in-class activity): video modules with embedded questions on how to use stoichiometric calculations to determine the limiting reactant in a reaction, what the theoretical yield is for a reaction, how much excess reactant would remain in a reaction, and how to determine the percent yield of a reaction; online quiz due prior to in-class activity.

-In-class activity: students were instructed to work in collaborative groups of 3-4 students and completed the activity sheet on using stoichiometric calculations (these calculations were based on published reactions developed to produce liquid fuel from coal); selected problems from activity sheet were assessed using a whole-class clicker/polling system.

Appendix 3. Reliability and test item analyses for the pre/post-test items. Responses for all test items for all students were coded 1 = correct and 0 = incorrect. Item means, item-total correlations, and Cronbach's α values were obtained using the Reliability Analysis tool in SPSS.

Table 1. Coefficient alpha and test item analyses for post-test questions. The item-total correlations and coefficient alpha values were calculated separately for each activity post-test (e.g., the item-total correlations for the Nuclear Atom post-test items were calculated using only the five items from the Nuclear Atom post-test, the item-total correlations for the Coulomb's Law post-test items were calculated using only the five items from the Coulomb's Law post-test, etc.).

Post-test (n=231)					
Activity	**Question**	**Mean**	**SD**	**Item-Total Correlation**	**Coefficient alpha (α)**
Nuclear Atom	1	0.91	0.29	0.491	0.91
	2	0.84	0.37	0.392	
	3	0.87	0.34	0.449	
	4	0.90	0.30	0.420	
	5	0.92	0.27	0.453	
Coulomb's Law	1	0.90	0.30	0.371	0.80
	2	0.76	0.43	0.344	
	3	0.81	0.39	0.369	
	4	0.75	0.43	0.385	
	5	0.71	0.45	0.395	
Atomic Interaction	1	0.88	0.32	0.434	0.98
	2	0.88	0.33	0.415	
Molecular Shape	1	0.75	0.43	0.257	0.61
	2	0.85	0.36	0.269	
	3	0.71	0.46	0.227	
Molecular Dipole	1	0.88	0.33	0.603	0.79
	2	0.85	0.35	0.521	
	3	0.65	0.48	0.390	
	4	0.75	0.44	0.551	

Note: Positive values for the item-total correlation indicate the individual question item is a good predictor of performance on the entire set of test items, and correlations > +0.20 indicate good agreement between test item performance and overall test performance (i.e., a larger positive correlation suggests better performance on the individual test item is correlated to better performance on the entire test). Values of coefficient alpha greater than 0.70 indicate acceptable levels of single administration reliability for the entire set of test items (coefficient alpha is often underestimated if the test has a low number of total test items).

Table 2. Coefficient alpha and test item analyses for post-test items included in the final exam. The item-total correlations and coefficient alpha values were calculated separately for each activity final exam/post-test (e.g., the item-total correlations for the Nuclear Atom final exam/post-test items were calculated using only the five items from the Nuclear Atom final exam/post-test, the item-total correlations for the Coulomb's Law final exam/post-test items were calculated using only the five items from the Coulomb's Law final/exam post-test, etc.).

Final Exam (n=231)					
Activity	**Question**	**Mean**	**SD**	**Item-Total Correlation**	**Coefficient alpha (α)**
Nuclear Atom	1	0.98	0.13	0.059	0.79
	2	0.98	0.15	0.160	
	3	0.98	0.15	0.174	
	4	0.98	0.15	0.133	
	5	0.97	0.18	0.187	
Coulomb's Law	1	0.99	0.09	0.182	0.62
	2	0.90	0.30	0.168	
	3	0.93	0.25	0.287	
	4	0.89	0.32	0.299	
	5	0.88	0.33	0.263	
Atomic Interaction	1	0.96	0.19	0.336	0.97
	2	0.96	0.20	0.348	
Molecular Shape	1	0.71	0.45	0.413	0.48
	2	0.68	0.47	0.271	
	3	0.53	0.50	0.348	
Molecular Dipole	1	0.94	0.25	0.306	0.45
	2	0.94	0.23	0.284	
	3	0.76	0.43	0.312	
	4	0.74	0.44	0.401	

Note: It is possible the decrease in item-total correlations for the Nuclear Atom test items and the Coulomb's Law test items 1-2 arose due to the fact there was a high rate of correct answer responses for all of the test items (e.g., the test item means ranged from 0.89-0.99). With these high item means, students who missed one of the test items was likely to have performed well on the other test items. This could have subsequently led to a lower item-total correlation (i.e., if a student missed just one test item, the performance on that individual test item would not correlate to their overall performance on the set of test items).

Table 3. Item means for pre-test items used for the five learning cycle activities. The item-total correlations and coefficient alpha values were calculated separately for each activity pre-test (e.g., the item-total correlations for the Nuclear Atom pre-test items were calculated using only the five items from the Nuclear Atom pre-test, the item-total correlations for the Coulomb's Law pre-test items were calculated using only the five items from the Coulomb's Law pre-test, etc.).

Pre-test (n=231)				
Activity	**Question**	**Mean**	**SD**	**Item-total Correlation**
Nuclear Atom	1	0.79	0.41	0.219
	2	0.54	0.50	0.245
	3	0.67	0.48	0.329
	4	0.69	0.47	0.400
	5	0.65	0.49	0.417
Coulomb's Law	1	0.86	0.35	0.110
	2	0.83	0.38	0.075
	3	0.75	0.43	0.270
	4	0.81	0.39	0.364
	5	0.84	0.37	0.378
Atomic Interaction	1	0.24	0.43	0.965
	2	0.26	0.44	0.965
Molecular Shape	1	0.26	0.44	-0.012
	2	0.57	0.50	0.012
	3	0.31	0.47	-0.083
Molecular Dipole	1	0.85	0.36	0.190
	2	0.79	0.41	0.216
	3	0.45	0.50	0.253
	4	0.43	0.50	0.092

Note: Incoming knowledge varied among the students based on previous exposure to chemistry in high school, and students who did not previously take a chemistry course would have limited preexisting knowledge. If a significant number of students had limited preexisting knowledge and were forced to guess on test items, this would be expected to result in lower item-total correlations (i.e., if students guessed correct answers for a specific test item, this would yield lower and possibly negative item-total correlations).

Appendix 4. Test items for each activity.

<u>Activity 1: Nuclear Atom</u>

Question 1. Which correctly describes the difference between Cu^{2+} and Cu^{+}?

A. They have a di□erent atomic number
B. They have di□erent number of protons
C. They have di□erent number of neutrons
D. They have di□erent number of electrons

Question 2. When considering a magnesium ion (Mg^{2+}), how many protons and electrons are present?

A. 14 protons, 12 electrons
B. 12 protons, 14 electrons
C. 12 protons, 10 electrons
D. 10 protons, 12 electrons

Question 3. Which correctly describes the difference between ^{19}F and ^{18}F?

A. They have a di□erent atomic number
B. They have di□erent number of protons
C. They have di□erent number of neutrons
D. They have di□erent number of electrons

Question 4. When considering the chlorine nuclide ^{35}Cl, how many protons and neutrons are present?

A. 17 protons, 17 neutrons
B. 17 protons, 18 neutrons
C. 18 protons, 17 neutrons
D. 18 protons, 18 neutrons

Question 5. Which part of the atom accounts for most the atom’s mass?

A. the nucleus
B. the neutrons
C. the protons
D. the electrons

Activity 2: Coulombs Law

Question 1. Which change(s) to two negatively charged particles would result in an increase in repulsive forces?

A. The particles are moved closer together
B. The particles are moved farther apart.
C. The particles are moved closer together and farther apart.

Question 2. What happens to the attractive forces between a positively charged particle and a negatively charged particle if the distance is decreased?

A. Attraction decreases
B. Attraction increases
C. There is no change in attraction

Question 3. If the distance is held constant, what happens to the attraction (force) between a positively charged particle and a negatively charged particle if the magnitude (size) of the charges is increased for both particles?

A. Attraction decreases
B. Attraction increases
C. There is no change in attraction

Question 4. Coulomb's Law would predict that the force of attraction would increase if:

A. The distance between two negatively charged particles is decreased.
B. The distance between a negatively charged particle and positively charged particle is decreased.
C. Both A and B are correct.

Question 5. Based on the simulation in the classroom activity, Coulomb's Law would predict that the force of attraction would increase if:

A. The magnitude (size) of charge on both the negatively charged particle and positively charged particle is increased.
B. The magnitude (size) of charge on each of two negatively charged particles is increased.
C. Both A and B are correct.

Activity 3: Atomic Interaction.

Question 1. When a chemical bond is broken, energy...

A. absorbed
B. released
C. neither absorbed nor released

Question 2. When a chemical bond is formed, energy…

A. absorbed
B. released
C. neither absorbed nor released

Activity 4: Molecular Shape.

Question 1. Which pair of molecules would you predict to have the same three-dimensional structure?

A. SO_2 and CO_2
B. NH_3 and BH_3
C. Both pairs of molecules have the same three-dimensional structure.
D. Neither pair of molecules has the same three-dimensional structure.

Question 2. Which would you predict to have the strongest repulsive force to a nearby electron pair?

A. A non-bonding electron pair
B. A bonding electron pair
C. These have the same repulsive force

Question 3. Which would you expect to have the smallest bond angle?

A. NH_3
B. CH_4
C. H_2O
D. These would all have the same bond angle.

Activity 5: Molecular Dipole.

Question 1. If the central atom in a molecule is bonded to two atoms of a different element, what would determine if the molecule is bent or linear?

A. the bonded atoms have a much larger electronegativity than the central atom.
B. the bonded atoms have a much lower electronegavity than the central atom.
C. the central atom has one or more pairs of non-bonding electrons.
D. the bonds are polar.

Question 2. What can you correctly conclude based on the electrostatic potential representation shown for formaldehyde?

A. The bonds are non-polar.
B. Electronegativities for all atoms are very similar.
C. The molecule has a net molecular dipole.
D. The electrons are evenly distributed throughout the molecule.

Question 3. Which explains why water molecules are polar and carbon dioxide molecules are non-polar?

A. water molecules have a non-linear molecular shape
B. carbon dioxide has non-polar bonds
C. both molecules have polar bonds
D. hydrogen and oxygen have a large electronegativity di□erence

Question 4. Which molecule has a net molecular dipole?

A. OCl_2
B. Cl_2
C. CO_2
D. BH_3

Appendix 5*.* Sankey diagrams for all test items.

Figure 1. Three-node Sankey diagrams for the assessment questions with more than 10% incorrect responses in the final exam. The diagrams display the flow of incorrect (red)/ correct (green) responses from pre-test (left node) to the post-test (middle node) and to the final exam (right nodes).

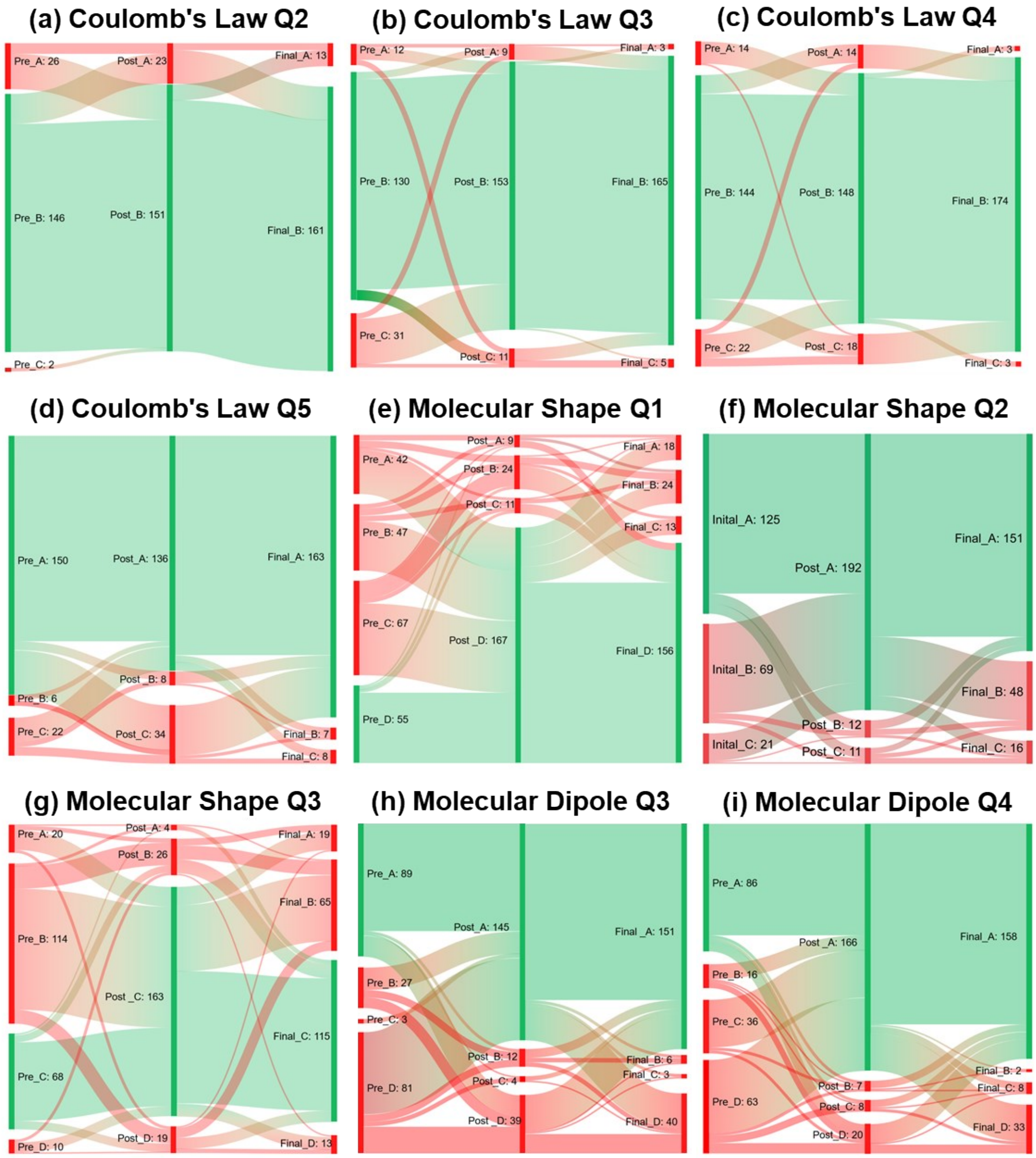

Figure 2. Sankey diagrams for the assessment questions with less than 10% incorrect responses in the final exam. The diagrams display the flow of incorrect/ correct responses from pre-test to the final exam.