Fostering discovery and innovation through problem-based learning and reinforcing experiences

Judith Giering, University of Virginia
Gail Hunger, University of Virginia
Linda Columbus, University of Virginia

Introduction

For years, STEM educators in higher education have been re-thinking and re-designing the way students are taught. Influenced by the work of many at the interface of education and STEM research and instruction such as Eric Mazur and Carl Wieman, institutions are creating powerful learning experiences for their students based on authentic, problem-based, and scale-up pedagogies (AAU, 2017 and Miller and Fairweather, 2016). The University of Virginia (UVA) is a Research I institution serving approximately 15,000 undergraduates and 6,000 graduate students. Although courses with innovative pedagogy are taught, these efforts have rarely converted to systemic, sustained curricular change especially for large classroom environments. The reasons are familiar to many institutions: lack of buy-in across a department, little or no incentive for faculty to undertake this work, and a struggle to find both the human and financial resources needed to be successful. The UVA Introductory Chemistry courses appear to be different and have scaled-up and sustained for several years and with several instructors. This article describes the process that was undertaken to tackle these barriers, the structure of the new courses, how the faculty and student experiences were assessed, and the outcomes after two years of implementation. In addition to enhancing the student experience and learning in Introductory Chemistry, the specific goal of removing all performance gaps among gender, race, and socioeconomic groups that have traditionally been observed in this course has thus far been achieved.

Background

The Introductory Chemistry curriculum is a two-course sequence taught in the College of Arts & Sciences (CAS), and also serves the School of Engineering and Applied Science (SEAS). Approximately 1300 undergraduate students enroll in Introductory College Chemistry I each Fall semester with ~700 from CAS and ~600 from SEAS. Introductory College Chemistry II, offered in the Spring, has an enrollment of almost 750 students with ~80 from SEAS and the remainder from CAS. Approximately 5-7% of the enrolled CAS students become Chemistry majors with the remaining students graduating with a variety of degrees (biology, psychology, and many in the humanities).

Up until the 2015-16 academic year, the courses were taught with a standard textbook and a traditional lecture style consisting of three 50-minute lecture sessions per week. Instructors typically held the rank of lecturer with at least three sections each taught by a different lecturer. Similar to many institutions, the Chemistry gateway courses at UVA had disproportionate DFW rates among different groups of students and the student experiences were variable with many overwhelmed with amount of content and the time commitment required of the courses. In 2016, one of the authors of this paper, a tenured research-active professor in the Department who had previously redesigned a year-long Biochemistry laboratory (Gray et. al, 2015) was asked to teach Introductory Chemistry. In addition to her commitment to incorporating best practices into her classrooms, she is engaged at the national level in both her scientific research and educational initiatives such as those of the AAU (Bradforth et al., 2015) and The Research Corporation for Scientific Advancement Cottrell Scholar Collaborative (Leibovich et. al, 2017 and Heemstra et. al, 2017). that this would lead to a greater pass rate and higher numbers of students persisting as Chemistry and STEM majors. For two years, a pilot study was conducted. There were 81 students enrolled in the first year, which grew to 200 students in the second year. Based on positive assessment data, in 2018, the pilot was expanded to 600 students with additional instructors in the third year, with continued assessment. Eventually, the team imagines that a significant percentage of students, and perhaps all of them, will take Introductory Chemistry in the new format.

Redesign of the Introductory Chemistry Curriculum

The literature suggests that active learning pedagogies are effective. Freeman et. al (2014), conducted a meta-analysis of 225 studies of examination rates of failure scores when comparing student performance in undergraduate science, technology, engineering, and mathematics (STEM) course under traditional learning versus active learning. The results indicate that average examination scores improved by about 6% in active learning sections, and that students in classes with traditional learning were 1.5 times more likely to fail than were students in classes with active learning. Less than 40% of US students enter university with an interest in STEM, and just 20% of STEM-interested underrepresented minority students finish with a STEM degree. Thus, the course was designed with a blend of pedagogical approaches with a focus on increasing active learning approaches.

In addition to pedagogy, the content and framework of delivery were considered (Cooper et al, 2015). The content of the course was revisited with two specific considerations that have significantly changed over the last decade (i) access to information and (ii) quality content available through online video instructions (e.g. Kahn Academy). In other words, what could Introductory Chemistry offer students that wasn't readily available to them for free? The design aimed to include the learning goals that were identified by the authors and the faculty in the Chemistry department as we conducted needs assessment meetings with the department. Faculty stated that their goal was to engage students in the discovery of chemistry so that students could experience how to "think like a chemist" and they wanted students to appreciate that chemistry still was being discovered and researched. Thus, based on the information below, we designed a problem-based component, with authentic activities, which would be taught using active learning in an active learning space for student engagement. Specifically, the faculty stated they wanted students to conduct inquiry and construct knowledge that would help them achieve the following:

- Acknowledge that chemistry is still being discovered and there are still unknowns,
- Introduce integrated concepts rather than isolated topics,
- Make the course less about memorization and more about thinking through different solutions to develop problem solving skills,
- Provide more accurate descriptions of the different areas of Chemistry and the different areas/careers chemists have (beyond medicine),

- Better prepare and expose students to what the future higher-level classes in chemistry include, and
- Deliver authentic instruction to connect the relevance of chemistry the students are learning to what they observe in the world,
- Design an introductory chemistry course that the entire department participated in the setting of core goals for the course.

Even with the pedagogical goals well-defined, a number of challenges needed to be addressed in order to realize these changes. An important partnership was established by the professor with the Learning Design & Technology (LDT) team (each of which are co-authors of this paper). Through this partnership, a number of challenges were identified and processes developed or resources obtained that would help to ensure the success and sustainability of the project:

Assistance to the faculty member to design and deliver the curriculum. A post-doctoral fellow co-taught, managed, and contributed to the development of the course content and instructional tools used. This position required funding from the department, the College, and the Provost's office.

Advocacy with College leadership. The faculty member worked in collaboration with the LDT director and senior instructional designer to gain support of the development of this course and all the new components for re-designing the course. The LDT facilitated conversations between the faculty member, department and the dean's office for continued and ongoing support. Semester updates were prepared by the team and distributed to continually involve the department and leadership in the development of the course.

Instructional design support. Instructional design support from LDT is provided as an ongoing component of the re-design and scaling up of this course. Weekly meetings with the team to determine curriculum, management, technology and active learning space components are continuously reflected upon for process improvement.

Invitation to department faculty to provide feedback on the re-design. A critical component to the sustainability of the course re-design was the inclusion of the department's faculty from the outset of the design. Initial engagement began with two participatory meetings to understand what concepts faculty considered essential for introductory chemistry. Each semester, the design team presented the design and assessment data. Students enrolled in the course participated in the conversations and answered faculty questions about what they did and didn't value in the course.

Use of an active learning classroom. Problem-based learning sessions, called Expos, were held in an active learning classroom that holds 99 students. The design of the space, including scale-up tables, white boards, throwable microphones, and wireless projection from any mobile device, promoted the problem-based pedagogy adopted in the course. Working with LDT, the professor was able to ensure that the course could be scheduled in this scarce resource for the foreseeable future.

Project documentation and assessment. Learning gains were assessed using the midterms and the final exam. The final was divided into three parts that matched the content of the midterms. For each student, the performance on the midterm was compared to the performance on that portion of the exam. Student experiences were assessed using student evaluations and focus groups. Each student has ePortfolios from the products of the Expos and peer learning assistants grade and provide feedback. The quality of these products and the language used in the entries was evaluated to determine the range of understanding of concepts. Completion and correctness of online questions was used as formative assessment to guide the content focus of the lecture time.

Learning Design & Technology: Instructional Design Model

Learning Design & Technology (LDT) instructional designers worked with the chemistry team using a model based on the principles of articulating intentionality, designing authentic courses, and cultivating engagement. This model became a model of instructional design anchored in a faculty community of practice. Bereiter and Scardamalia (1989) define intentional learning as cognitive processes that have learning as a goal rather than an incidental outcome. Intentionality in learning design also calls attention to the sometimes-conflicting interactions between what is ‘explicit’ and what is ‘hidden’ in the curriculum. Reeves and Oliver (2014), state that, “Authentic learning typically focuses on real-world, complex problems and their solutions, using role-playing exercises, problem-based activities, case studies, and participation in virtual communities of practice. It offers students opportunities to research issues, think critically, gain new perspectives, solve problems, and develop written and oral communication skills guided by engaged and involved faculty.” The Glossary of Education Reform defines student engagement as “the degree of attention, curiosity, interest, optimism, and passion that students show when they are learning or being taught,” which extends to the level of motivation they have to learn and progress in their education. Through this model, the redesign of the course was facilitated. Throughout this model, faculty members reflected upon the student learning experience and shared ideas and concerns. It continues to be an iterative process.

Course Overview

There are approximately 1300 undergraduates enrolled in introductory chemistry. Traditionally, students were divided into three sections that met three times a week for 50 minutes with the instructor and a discussion section with a graduate student that met for an additional 90 minutes. A standard textbook was used along with an online questioning tool for reinforcement of material and feedback. Feedback from meetings with departmental faculty suggested that some degree of lecture needed to be retained in order to explain complex concepts, so the question became how to balance this with a student-centered, active approach to learning. We used Kuh’s (2008) high-impact practices as a model for student engagement and the principles of authentic instruction (Herrington and Oliver, 2000) as a guide for developing problem-based sessions that incorporate real-world relevance; ill-defined activities; opportunities for students to define their own tasks; are sustained over time for investigation; provide the opportunity to collaborate; and can be integrated across subject areas.

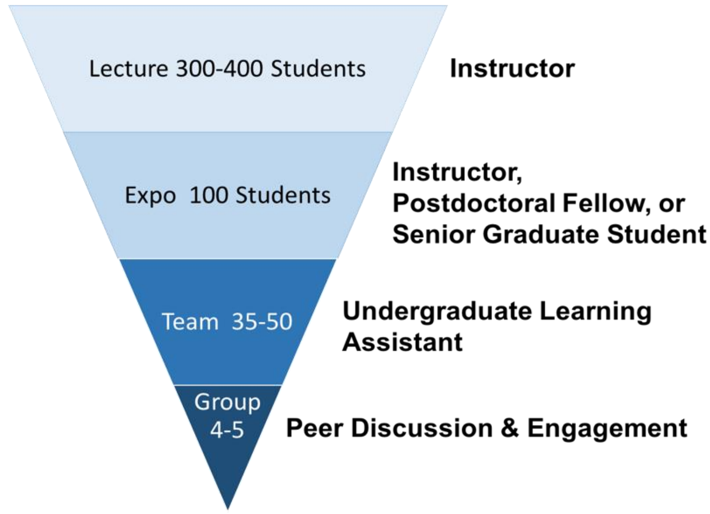

Figure 1. A schematic of the organization of the number of students and instructors in the redesigned introductory chemistry course.

The course structure was designed for flexibility in staffing the increased number of sections compared to the traditional lecture and associated discussions sections (Figure 1). The new courses consist of one 75-minute lecture per week, with up to 300 student and one 75-minute problem-based learning session per week, called an Expo, with 99 students. A professor or instructor delivers the lecture and the Expos can be facilitated by professors, instructors, postdoctoral fellows, and senior graduate students. The training of the future generation in active learning practices is an additional outcome of the course design. This year with the scale-up, additional undergraduate learning assistants were introduced such that we could develop learning communities among the students in each Expo. Within the Expos, enrolled students form teams of 4 – 5 students (2 groups per table) that last an entire semester.

The weeks have a consistent schedule (Figure 2) of assignments that introduce, reinforce, and revisit the weekly content.

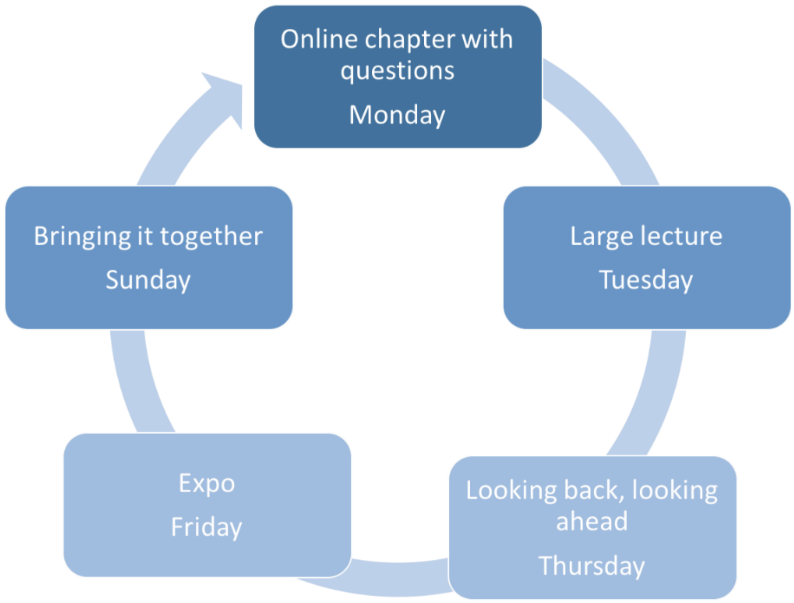

Figure 2. The weekly structure and assignments in the redesigned introductory chemistry course.

Textbook. The online textbook was created from existing sources of introductory, organic, and physical chemistry content. The focus in creating the text was to reduce the amount of content and provide more integrated and in-depth exploration of concepts. For instance, the concept of energy was integrated into almost every chapter. After every few paragraphs in the text multiple choice questions were assigned to reinforce the material. The responses are graded half on participation and half on correctness. Additional material was added online to connect to the exploration activities, which were also included into the online textbook.

The Lecture. Before the first meeting, the students read the chapter online with questions embedded every two paragraphs examining their understanding of the material. The questions are assessed for both participation and correctness. This assignment is due at 11:59 pm before the day of the first class. The instructor then delivers a lecture focused on the more challenging material and includes the questions in the chapter that the students didn't answer correctly. During the lecture the professor engages students with a 'think, pair, share' question using a web- based polling system. Students are encouraged to share their thinking and questions. Teaching assistants facilitate questions and ensure students can ask questions in the large lecture using a throwable microphone. Following the lecture and before the Expo, a second assignment for the week called "Looking Back and Looking Ahead" has additional graded practice questions from the material in the chapter, as well as questions to prepare their thoughts and materials for the second class that meets later in the week and asks them to anticipate what might come next in the curriculum.

The Expo. The critical component to the new version of Introductory Chemistry are the problem-based Expos. Each week, the Expos is a guided set of questions that engage students in discourse and problem-solving focused on the content of the week. During the Expos, students work in small groups to complete problem-based activities and report out on their results. An example of an Expo is provided in Appendix I. After the Expo, there is the final assignment called "Bringing It Together" which includes posting the work products from the Expo with an analysis or answers to guiding questions in an e-portfolio for reflection, more practice questions, and having students find real world applications or understanding of the material. The learning environment of the Expos was designed to support and challenge the learner's thinking. Students work in small groups in an active learning classroom, solve problems on whiteboards, and present their ideas and thinking to the entire class. Students are also provided opportunities for analysis on the content learned and their learning process. They use ePortfolios to reflect on their Expo experience and lecture content each week. An assignment titled "Bringing It Together" includes specific assignments to include in the ePortfolio and follow-up graded questions. Students write, draw, audio/video record their thinking and put in their ePortfolio.

The following elements guide each Expo session:

- *Real-world relevance.* The course was designed using an e-book so that all activities mirror the kinds of topics and problems chemists face in their discipline. The emphasis of this text is to have students engage think like a chemist as opposed to learning chemistry content.
- *Ill-defined activities and opportunities to collaborate.* In place of content as the primary driver for learning, complex and ill-defined activities were created for the Expos. Presented in the e-book, students had to work on these problems, both individually and in their group and present their findings and strategies. For each problem, students are asked to determine a course of action or interpretation and generate their own ideas. Expos are highly collaborative and give students the opportunity to test their thinking in chemistry.
- *Sustained thinking over time and integration of content across subject areas.* The resulted in re-framing where introductory chemistry fits into the overall field of chemistry and focusing critical thinking vs content. Students gained experience and confidence in explaining complex topics in both small and large group discussions and were encouraged to make connections with other topics such as mathematics, biology, and statistics.

Exams. There are three midterms and a final. Midterm exams are designed with engagement and high-risk low penalty assessment in mind. There is an individual and group component to the midterm. The individual component is taken online by the student and has two parts: (i) a set of standard multiple-choice questions similar to what they have seen on all previous assignments and (ii) six - seven multiple choice questions which are very in-depth for which the content is not easily searched online or in a textbook. The students are given several days to take the exam and the only requirement is that they not talk to any other individual about the exam. With the individual component of the exam complete, the students come to the Expo section and take the part (ii) of the exam in a group. All exams are cumulative. Over the course of the midterms, the individual component of the exam is worth more. The final exam has no group component and is closed book and notes. The midterms are the most unique aspect of the course and highlight the level of engagement integrated throughout the course design.

Chem Test Video

Video 1. Video clip demonstrating student engagement during the Group component of the midterm.

Student Engagement. Group work is critical in the redesigned Introductory Chemistry courses. A student is in the same group all semester in order to build confidence, comfortability, and community that facilitate engagement and learning. During the Expos, the instructors and teaching assistants are monitoring (i) whiteboards for content and progression through the assignment, (ii) the answers the students submit online, and (iii) the scientific conversations within the groups. The chemical language the students are having indicates a level of engagement that is difficult to imagine facilitated in the standard lecture format.

What does it look like to be a student in the new Introductory Chemistry course? Figure 3 provides several examples of how students were engaged in their work in the Expos.

Figure 3. Pictures of student engagement during the Expo portion of the course.

Assessment

A robust assessment plan was developed to measure multiple aspects of the re-design. The purpose of the study was gain feedback about the redesign of Introductory Chemistry, specifically as it relates to student learning and engagement.

Multiple methods of data collection were used for the study:

- Pre/post testing to measure student learning each semester
- Surveys to measure student's perception of their learning, the learning environment, and attitudes
- Focus groups to ask in depth questions based on the outcomes of the surveys
- Interview with the post-doctoral fellow

This study collected data to guide our decisions to design a successful course and use the aggregated data collected to support the dissemination of our approach to other Chemistry departments. Dissemination of the aggregated data would be published in chemical education journals and brochures advertising the curriculum. Participants enrolled in CHEM 1410 and 1420 and 1810 and 2820 (Introductory Chemistry I and II and the accelerated versions, respectively) will be asked to participate in the study. Estimated number of participants: 270 each semester (across sections).

With IRB approval (#2016-0388-00), we documented the student experience using photographs and video recording. Our intent will be to share the data and findings on a UVA website for teaching and learning purposes only in order to inform the department about the re-designed course.

Student Evaluation Data

Retention. 94% of the students were retained for the second semester as compared to 78% in the traditional sections (not including the engineers in this calculation since the second semester is not required) and 49% in the Honors track series.

Student Evaluation. The student evaluations are a valuable tool to evaluate the student experience. Appendix II summarizes the student responses to the standard Likert-style evaluation questions given by the University (textbook questions were removed since we didn't use a traditional textbook). The large standard deviations prevent comparisons between the redesigned course and the traditional lecture course; however, overall, both approaches were evaluated positively. The write in responses were sorted into three different categories based on the tone of the comment: positive and/or neutral, negative, and mixed. The majority of the students wrote positive or neutral comments (Figure 4). An example of each category is provided (short responses were chosen):

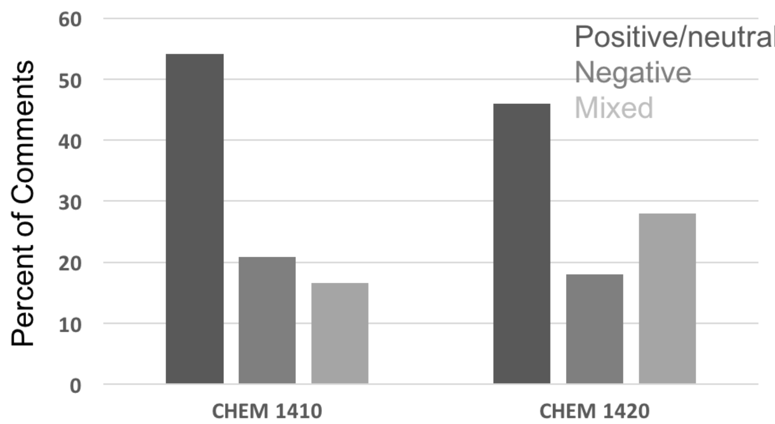

Figure 4. Percent of comments that were positive or neutral, negative, or mixed in the tone of the review. The number of comments were 24 for CHEM1410 and 50 for CHEM 1420.

Positive: I came into this class incredibly nervous of how I would do, but now I am wrapping up the first semester understanding more about chemistry than I thought would be possible. I'm looking forward to continuing this class next semester, and I hope to have more classes with Professor Columbus in the future.

Neutral: This course is different from the others but it didn't take away from learning.

Negative: I found myself confused by the subject material often. I don't think the concepts were explained very clearly.

Mixed: The learning style is better than sitting in lectures, but trying to understand certain topics was hard because we didn't spend much time on them.

Student learning gains. The final exam is traditional in design compared to the midterms. Despite the different format, the students performed well (Figure 5). To assessing learning gains over the semester, the final was divided into three parts with each comparable to one of the three midterms. Although the midterm exams are more challenging than the final exam in terms of detail and level of analysis required, the final was divided into content that could be directly compared to the individual exams given during the semester. for each semester of the course, learning gains were assessed with the final exam compared to each of the midterm grades (Figure 5, only the individual performance was used in this assessment). Any student that performed better on the final than the midterm will be represented by a data point above zero; thus, a quick analysis can be made by looking at the total number of data points above zero. The majority of the students performed better on the final than the midterm for the content covered in the first and second third of the semester. The third and last midterm is taken the last week of classes and learning gains are not as strongly reinforced to improve performance on the final.

The students retained and improved their understanding of the tested concepts as long as they had some amount of time that reinforced the material between the midterm and the final. Overall the trend indicates that the material learned and reinforced over the semester was the content the students performed the best on at the end of the semester.

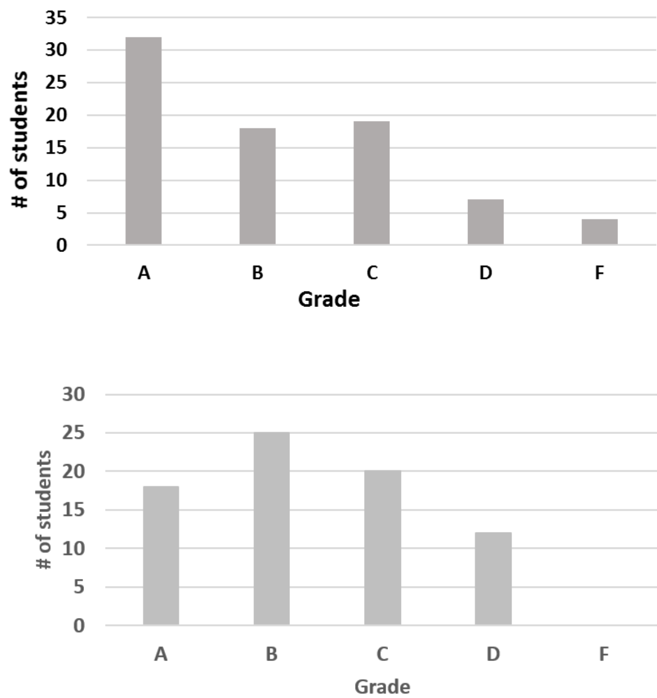

Figure 5. Grade distribution for the final exam for CHEM 1410 (top) and CHEM1420 (bottom) with the new curriculum.

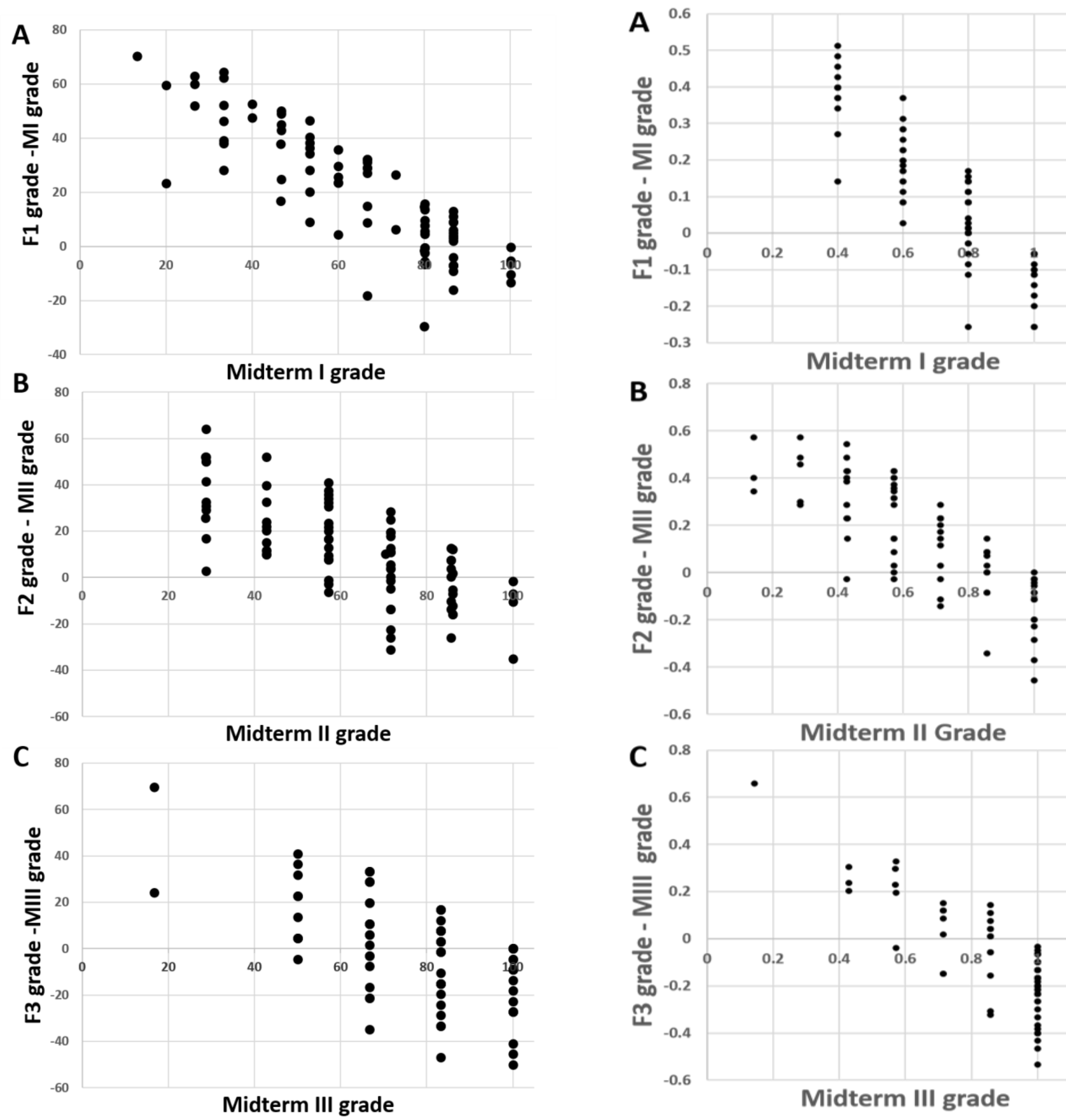

Figure 6. Student learning gains on the final compared to each of the midterms in the first semester (CHEM1410; left column) and the second semester (CHEM1420; right column). The y-axis of these plots is the midterm grade subtracted from the final exam grade corresponding to the appropriate material.

Focus Group Data. Over sixty students attended a focus group session and engaged in an action research study about their experience in the course. The questions were "What went well?", "What did not go well?", and "What suggestions for improvement do you have?". Students unable to attend answered the same questions in an online survey. Overall, students expressed they were constantly engaged in this class and it was beneficial to their learning. In terms of “What went well” students thought the lectures were thought provoking informative. They thought the tests challenged them to apply their knowledge and they were fair. They thought the individual and group tests were a great learning experience. They thought the course provoked them to think about how chemistry was applied and it was a great learning atmosphere. Students also expressed that in the active learning rooms for Expos, they felt like their instructor knew them and felt like they could really talk about chemistry. “What did not go well” was expressed in terms of an overload of the use of new tools. They also expressed the need for a better e-book. For “Recommendations” students suggested short quizzes for recall and conceptual understanding throughout the semester.

Next Steps: Inclusive Practices

A large amount of literature indicates the traditional chemistry curriculum does not promote success among all students. An inclusive curriculum considers student’s experiences, impairments, and well-being and ensures equality in learning and teaching (Morgan & Houghton, 2011 and Association of American Colleges & Universities, 2015). An inclusive curriculum is anticipatory, flexible, accountable, collaborative, transparent, and equitable (Morgan & Houghton, 2011). Large classes are inherently inflexible and non-collaborative. This redesign addresses all aspects of an inclusive curriculum with an emphasis on collaboration, flexibility, and open communication. Specifically, (i) group work, (ii) problem-based learning, (iii) reflections on learning and content, and (iv) explicit content and communication about the expectation that all students in the class can perform well and could become scientists if they want to are used throughout the course to aim for an inclusive curriculum. With the scale-up to 600 and more students, the evaluative and assessment data is being collected to ensure performance gaps are not occurring in different student populations (e.g. first generation, socioeconomic status, race and gender).

Conclusion

We believe this re-designed Introductory Chemistry course can serve as a model for other introductory STEM courses. The problem-based model demonstrates the relevance of chemistry to all students with rigor and depth. There are three critical aspects to the redesign that can be used as a model for the development of other large STEM courses: (i) inclusive process that included faculty, staff, and students for departmental buy-in, (ii) data within the collection to determine areas of improvement and success and (iii) team-based design approach to distribute expertise and workload required for the development and implementation of the course. Our process established an effective and sustained redesign of a large introductory STEM course and can be modeled to re-designing other STEM disciplines so that students will experience success and discovery. Going forward, we are working with the Provost’s office to conduct different assessments to measure how this re-design impacts the DFW rates, learning, and experiences of different student population.

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Appendix I: Example Expo Activity

Chemistry Exposed

Molecular orbitals

Objectives

1. Visualize linear combination of atomic orbitals as bonds

2. Understand the atomic interactions that dictate bond formation

3. Compare trends in molecular orbitals and associated energies between molecules

4. Using molecular orbital theory, determine if a molecule can form and if the molecule is diamagnetic or paramagnetic.

5. Understand what determines orbital mixing

6. Continue to hypothesize about the correlation(s) of orbital energies and shapes with molecular stability/reactivity.

Activities

Be sure to take notes using your notepad here in Top Hat so you can answer the BIT questions and review for the exams.

1. Energy and visualization of molecular orbitals of diatomic molecules.

1.1 On the dry erase board, sketch the N atomic orbitals and the molecular energy diagram for N_2 diatomic molecule. The sketch should look like those found in your text book.

1.2 Upload an image of your energy diagram for N_2 with drawings of the molecular orbitals to the weeks four tab of your ePortfolio.

CH04:Expo Q01

Is N_2 stable?

A	Yes
B	No

CH04:Expo Q02

What information allowed you to answer the above question?

A	There are more electrons in the antibonding orbitals than the bonding orbitals. Thus, the bond order is greater than zero and the molecule is stable.
B	There are more electrons in the bonding orbitals than the antibonding orbitals. Thus, the bond order is greater than zero and the molecule is stable.
C	The energy of the lowest occupied orbital is below zero. Thus, the bond order represents a stable molecule.
D	The energy difference between the 2s mixed orbitals is lower than the 2p orbitals. Thus, the molecule is stable.

CH04:Expo Q03

Is N_2 paramagnetic or diamagnetic?

A	diamagnetic
B	paramagnetic

CH04:Expo Q04

What feature of the molecular orbital diagram allowed you to answer the previous question?

A	All electrons are paired in the molecular orbitals.
B	There are electrons in the antibonding orbitals that are formed for the mixing of the atomic p-orbitals.
C	There are unpaired electrons.
D	The orbitals formed for the mixing of the 2s atomic orbitals are occupied.

CH04:Expo Q05

What is the bond order of N_2?

A	3
B	2
C	1
D	0

CH04:Expo Q06

Based on the bond order what type of bond does N_2 have?

A	no bond, it is unstable
B	single
C	double
D	triple

1.3 Build N_2 in Spartan. Use the information above in terms of the type of bond to build between the two nitrogen atoms .

1.4 There are two inputs that you need to consider before you build N_2 in Spartan:

CH04:Expo Q07

What is the charge of N_2?

A	-1
B	-2
C	neutral
D	+1
E	+2

CH04:Expo Q08

How many unparied electrons does N_2 have?

A	none
B	1
C	2
D	3

1.5 Calculate the orbital energies and shapes (Use Equilibrium Geometry, orbital model B3LYP (an approximation of the Schrödinger equation, and basis set 6-31G*) for the calculation).

1.6 When the calculation is complete look at the orbital energy diagram and the shapes of each molecular orbitals.

CH04: Expo Discussion 01

What is different between your molecular orbitals and energy diagram and that you see in Spartan?

Responses

Reply

Ordered by Newest Responses

CH04:Expo Q09

Multiple answers: Multiple answers are accepted for this question

Which of the following highlights a major difference between your molecular orbital diagram and the one calculated with Spartan (check all that apply)?

A	there are two columns labeled a and b
B	the 2s bonding orbital is not shown
C	there are actual energy values assigned to the orbitals
D	the bonding orbital that arises from the two pz atomic orbitals doesn't look like how we or the book draws it

CH04:Expo Q10

Multiple answers: Multiple answers are accepted for this question

What additional information do you obtain with Spartan that you could not have in your sketched diagrams (select all that are correct)?

A	energy values
B	more accurate estimates of the mixing of the atomic orbitals to form the molecular orbitals
C	more accurate representation of the shape of the molecular orbitals
D	Spartan provides the exactly right representation of the molecular orbitals and their energies

1.7 On graph paper, plot the N_2 HOMO and LUMO calculated by Sparten. Label each MO with the type of orbital it is. Be sure to label your x- and y-axes.

1.8 On the dry erase board, sketch the molecular orbitals and energy diagram of O_2. You should be able to use the N_2 MO diagrams and modify based on the difference in electron configuration (e.g. the difference in the number of electrons between N and O) and properties that control atomic orbital mixing.

1.9 Calculate the molecular orbitals of O_2 with Spartan.

1.10 Lets try to make sense of Spartan's calculation. If you can get through this even in a confused state you have demonstrated you have an accurate concept of bonding. Consider that a and b refers to alpha and beta spin states (up and down; +1/2 and -1/2). Do the orbital shapes and order match your sketch?

Ughhhh, why does the professor want to complicate everything? Why are we using a program that isn't RIGHT. Spartan is computing an approximation that is more accurate than the LCAO method that you are attempting to visualize with paper and pencil. However, there is no RIGHT in science, there is just getting to a better understanding.

1.11 Draw the HOMO and LUMO MO diagram from Spartan of O_2 on the same graph paper you plotted N_2. Label each level with the type of orbital it is. You can decide how you want to treat the alpha and beta MOs of oxygen as long as you explain what you do and why.

CH04: Expo Question 11

What is the bond order for O_2?

A	0
B	1
C	2
D	3

CH04: Expo Discussion 02

Which do you think is more stable N_2 or O_2? Why? Use more than one reasoning.

Responses

Reply

Ordered by Newest Responses

CH04: Expo Discussion Q03

Using data from today, discuss why we might have evolved to breath O2 instead of N2.

Responses

Reply

Ordered by Newest Responses

Appendix II

Table 2. Provost designed student evaluation responses for CHEM1410		
	CHEM1410 (N=42)	Chemistry Lecture (N=1282)
The lecture material was presented clearly.	**3.76 ± 0.88**	**4.15 ± 1.04**
The professor seemed well organized.	4.02 ± 0.72	4.28 ± 0.93
The professor seemed enthusiastic about teaching this course.	4.79 ± 0.42	4.54 ± 0.75
The professor seemed to have a good grasp of the subject matter.	4.6 ± 0.59	4.68 ± 0.57
The professor was able to explain the subject matter in a way that helped me to understand even difficult topics.	**3.43 ±1 .13**	**3.89 ± 1.25**
I consider this professor to be better than average when compared to other University of Virginia faculty members from whom I have taken courses.	3.71 ± 1.01	3.88 ± 1.22
The quiz dates were announced well in advance.	4.55 ± 0.63	4.42 ± 0.78
The quiz questions concerned the most important aspects of the course material.	3.95 ± 0.92	3.89 ± 1.02
The quiz questions were stated clearly.	3.48 ± 1.02	3.82 ± 1.03
Sufficient time was available to answer each quiz question to the extent that my knowledge of the material would permit.	4.33 ±0 .69	4.14 ± 0.92
The quizzes were graded and returned promptly.	4.36 ± 0.73	4.16 ± 0.9
My quizzes were graded fairly.	4.26 ± 0.73	4.18 ± 0.83
The extent to which help was available (faculty or teaching assistant office hours, review sessions) was sufficient for my purposes.	4.43 ± 0.63	4.22 ± 0.60
The workload is commensurate with the level of the course and the credit hours received.	**4.29 ± 0.6**	**3.99 ± 1.01**
I believe this course delivered the kind of quality education I expected to receive when I enrolled at the University of Virginia.	3.76 ± 1.21	3.96 ± .11
I learned a great deal in this course.	3.95 ± 0.96	4.06 ± 0.96
Overall, this was a worthwhile course.	3.98 ± 1.02	3.96 ± 1.07
The course's goals and requirements were defined and adhered to by the instructor.	4.27 ± 0.71	4.38 ± 0.77
The instructor was approachable and made himself/herself available to students outside the classroom.	4.52 ± 0.71	4.23 ± 0.91
Overall, the instructor was an effective teacher.	3.98 ± 0.92	4.12 ± 1.15

5 – strongly agree, 4-agree, 3-neutral, 2-disagree, 1-strongly disagree

Table 2. Provost designed student evaluation responses for CHEM1420		
	Expo redesign (N=67)	Chemistry Lecture (N=851)
The lecture material was presented clearly.	3.83 ± 0.99	4.08 ± 1.01
The professor seemed well organized.	4.12 ± 0.83	4.24 ± 0.92
The professor seemed enthusiastic about teaching this course.	**4.85 ± 0.36**	**4.49 ± 0.84**
The professor seemed to have a good grasp of the subject matter.	4.66 ± 0.51	4.67 ± 0.59
The professor was able to explain the subject matter in a way that helped me to understand even difficult topics.	3.98 ± 0.90	3.86 ± 1.22
I consider this professor to be better than average when compared to other University of Virginia faculty members from whom I have taken courses.	4.01 ± 1.01	3.87 ± 1.23
The quiz dates were announced well in advance.	4.49 ± 0.74	4.47 ± 0.77
The quiz questions concerned the most important aspects of the course material.	3.93 ± 1.03	3.94 ± 1.02
The quiz questions were stated clearly.	**3.29 ± 1.13**	**3.83 ± 1.04**
Sufficient time was available to answer each quiz question to the extent that my knowledge of the material would permit.	4.34 ± 0.78	4.14 ± 0.98
The quizzes were graded and returned promptly.	4.24 ± 0.82	4.25 ± 0.88
My quizzes were graded fairly.	4.04 ± 0.84	4.13 ± 0.90
The extent to which help was available (faculty or teaching assistant office hours, review sessions) was sufficient for my purposes.	4.28 ± 0.79	4.16 ± 0.98
The workload is commensurate with the level of the course and the credit hours received.	**4.36 ± 0.63**	**3.86 ± 1.18**
I believe this course delivered the kind of quality education I expected to receive when I enrolled at the University of Virginia.	3.89 ± 1.10	3.87 ± 1.17
I learned a great deal in this course.	3.97 ± 0.96	4.09 ± 0.98
Overall, this was a worthwhile course.	4.10 ± 0.88	3.95 ± 1.12
The course's goals and requirements were defined and adhered to by the instructor.	4.43 ± 0.66	4.39 ± 0.77
The instructor was approachable and made himself/herself available to students outside the classroom.	4.40 ± 0.70	4.23 ± 0.98
Overall, the instructor was an effective teacher.	4.20 ± 0.81	4.11 ± 1.13

5 – strongly agree, 4-agree, 3-neutral, 2-disagree, 1-strongly disagree