Team-Based Learning and Open Educational Resources in Honors Chemistry

Report Summary

In Fall 2011, students qualified to enroll in Honors Chemistry (Chem 43) were offered the opportunity to enroll in a section taught by Dr. Stephen Craig using Team-Based Learning™ (TBL) with electronic resources as an alternative to the traditional lecture and textbook section. Twenty-nine students enrolled in the redesigned course.

The goals of the course redesign effort were:

- To study the impacts of team-based learning techniques on student and faculty course experiences, specifically:
  - student pre-class preparation instead of lecture-based content delivery, and
  - student team problem-solving during class rather than lecture
- To explore the usefulness of assigning electronic course materials (including open educational resources) instead of a paper textbook
- To learn about student use of iPads for accessing course materials

This report describes the findings of preliminary assessment in this first semester of implementation, based on data gathered from multiple sources including a student survey (n=15, response rate = 52%), end of course evaluations, exam performance, interviews and classroom observations.

Findings

Team-based learning was viewed as a success by the instructor and by the students.

- Dr. Craig concluded that students learned effectively without a lecture or discussion section, because his students did just as well as those in the other section.
- No students transferred out of the team-based learning section, although this option was available to them throughout the semester (beyond the usual add-drop deadline).

Participant Comments on Team-Based Learning

"I learned that the students aren't necessarily thinking what I think they are thinking." – Steve Craig

"It motivates me much more to attend class, even though it's very early in the morning. It's nice being able to pull knowledge from all of our backgrounds." – Chem43 student

"I feel that the effectiveness of the team learning depends on the unit; certain units lent themselves more to discussing questions as members of a team (like in the molecular orbitals unit, when discussion definitely helped with understanding the concept!)." – Chem43 student

- The majority of students (10/15 survey respondents) would take another course taught using team-based learning.
- A slight majority of students (8/15 survey respondents) reported that they were learning as much in team-based learning as they would in a lecture-taught course.
- Average scores on blocks of exam questions that were identical between the team-based learning and lecture based sections were identical.
- A greater proportion of students in the team-based learning section continued in Chemistry the next semester.
- The instructor felt that team-based learning was a success; he plans to use team-based learning when teaching this course again and will collaborate with a colleague interested in teaching larger classes with team-based learning.

Students found the electronic course materials to be useful as a supplement to (but not a replacement for) the textbook.

- Selecting, reviewing, creating and editing videos and other e-resources for Chem 43 represented the largest and most significant area of effort for implementing this course redesign.
- Students rated text and images as the most useful materials (*13/15 respondents*); video resources were also rated as useful by a large majority of students (*lecture videos*, *12/15; worked problems, 10/15*).
- Most students reported using most of the e-resources assigned for the class (*11/15*).
- Nearly all survey respondents reported consulting the print textbook in addition to the online course content (*14/15*). Students cited a variety of reasons for using the textbook: more consistent flow of the materials; additional practice problems; and more control over pacing and focus with text and images (rather than video).

Student comments on Course Materials

"Reading the textbook, which delivers the information in much more detail, has allowed me to learn the material at whatever pace I'm comfortable with. There's also an added benefit to learning the information from pictures, text, and problems on a page in addition to hearing the online lectures, and doing the numerous practice …in solidifying my understanding …."

"Really liked the team-based learning aspect. However, was not fond of learning material individually through unreliable online resources. Material selected from online resources needs to be easier to understand and less time-consuming (had to go through too many links just to learn the material)."

iPads were made available to all students to facilitate convenient mobile access to the electronic course materials. Some students preferred using laptops to access the electronic course content; others preferred using the iPad.

- Students used a variety of hardware to access online course content including iPads, PC and Mac laptops, desktops, and smartphones. Some students reported that they did not try using the iPad for the class (4/15 survey respondents). Six students found the iPad useful or very useful for the class.

- All of the students who used an iPad also reported using a PC (n=7) or Mac laptop (n=2) to access course content.
- A majority of students (64%) reported that having an iPad did not make them more likely to use the electronic course materials.

The students and faculty reported positive experiences overall without sacrificing learning gains

The instructor found that students did just as well in team-based learning with minimal lecturing compared with a lecture-based course. In addition, the team-based learning section did not include a discussion section, so the students had fewer hours of class time. Student attendance was atypically high for an early morning class (90-95%), and high levels of student participation and engagement were the norm. Dr. Craig felt that he benefited from learning what the students are thinking during team exercises, noting that this format gave him more insight into students' thinking than he felt he would have had in a lecture-based course. Finally, Dr. Craig observed that most student teams had a positive group dynamic, and frequently these assigned teams carried over into out-of-class study groups.

Assessment of future courses using team-based learning could include assessment of growth in student skills in the area of teamwork, collaboration skills, or other significant outcomes not included in this initial assessment. Other potential outcomes of the team-based learning approach will not be possible to assess for another 1-2 semesters (i.e. continuation and achievement in subsequent chemistry courses).

Academic tools are not yet available to support team-based learning on a larger scale

Dr. Craig and others involved in supporting this course identified academic technology that would be needed to use team-based learning in larger classes. Faculty need technology tools to facilitate the time-consuming administrative aspects of team-based learning. Specifically, faculty need tools to automate peer assessment, group grading on quizzes and assignments, administering immediate feedback tests and the flexibility to include all aspects of team-based learning in assessing students. In addition, faculty and students would benefit from simple and efficient ways to capture and share feedback on the learning resources such as student ratings and usage. These learner analytics would enable faculty to respond to student needs, and would enable students to effectively manage their learning.

Report Contents

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The students in Chem 43
Trinity College Office of Assessment
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Detailed Report

About the course: Chem 43 Honors Chemistry

Honors Chemistry, Chem 43, is open to students who meet prerequisite requirements (a score of 4 or more on the AP Chemistry exam and more than 1 year of high school chemistry). Honors Chemistry has historically been a large lecture course (including weekly recitation and laboratory sessions) taught to over 100 students. The laboratory contributes 20% to the final grade; the remainder of the final grade has been based on exam grades (3 midterms and a final). Exams are composed of problems to be solved rather than multiple choice. Dr. Craig describes the opportunity he saw to revise this course:

> "In my teaching of first year chemistry, I loved the students but did not like the large lecture course. The best moments in that course were not in lecture but in office hours or outside of class. Duke is defined by the people who are here, both faculty and students, and the interactions between us define the Duke experience. The goal of this course redesign was to explore structures that facilitate and emphasize that 'uniquely Duke' part of the experience, both interactions between the professor and the students and the peer interactions."

Prior to the start of the Fall 2011 semester, an alternative section was offered to all students enrolled in Honors Chemistry. Students received an email invitation (*see Appendix 1*); 40 eligible students volunteered. The faculty intended to limit the new section to the first 25 student volunteers, but accommodated 29 students in the alternate course. Students who described why they volunteered cited the professor's ratings, smaller class size and more interactive class time. One student said "It seemed like an exciting opportunity and a good way to transition from high school learning to college learning."

Description of the alternate section of Honors Chemistry

The Honors Chemistry course was redesigned around a series of learning objectives (*see sample learning objectives in Appendix 2*). Chemistry personnel (*see box, right*) worked together to state the learning objectives, and then select or create electronic educational resources to help students achieve the learning objectives.

On the first day of class, students were assigned to teams of 5 to 7 students, named their teams, negotiated a grading scheme for the course (*based on guidelines distributed by Dr. Craig – see Appendix 3*) and discussed the peer review criteria for the members of each team. In the first discussion section, iPads were distributed to the students in the course to use with the online course materials. The remainder of the scheduled discussion sessions were replaced with optional office hours.

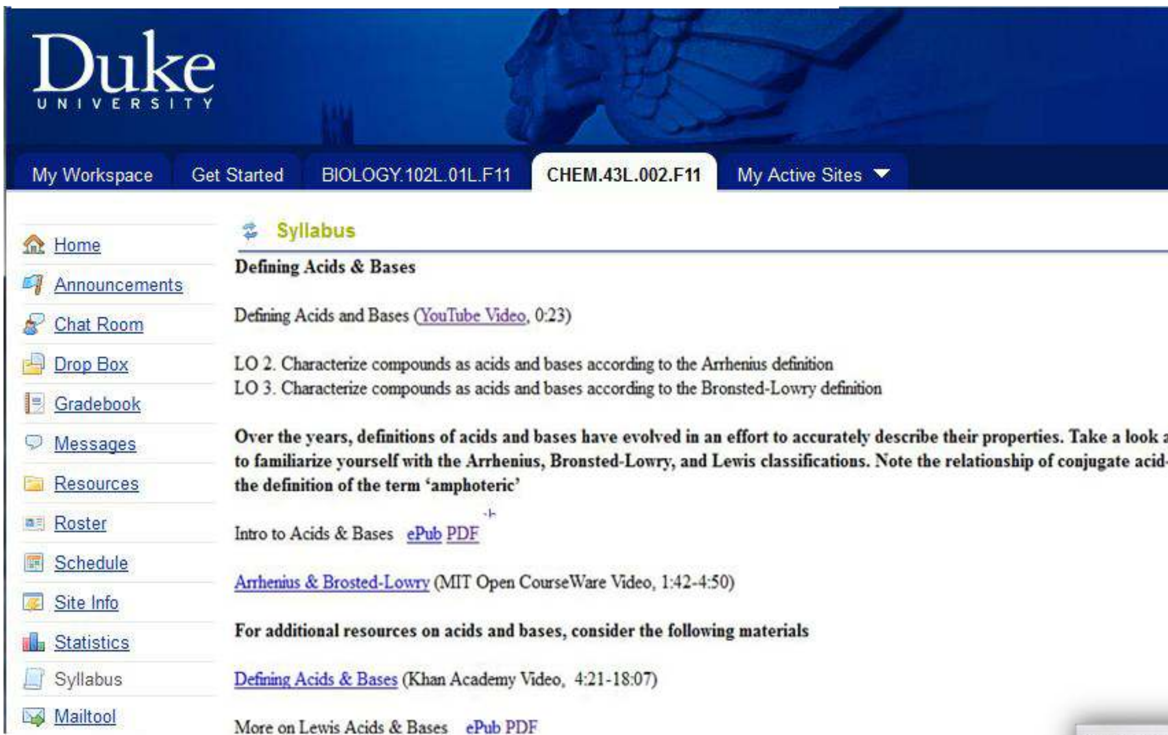
In subsequent class meetings, students actively solved problems in their teams, which remained constant throughout the semester. The course design followed Team-Based Learning™ as described in Michaelsen, Knight and Fink (2004).

The Chemistry team

Stephen Craig, Professor and Project Lead
Amanda Kasper, Instructor
Richard MacPhail, Associate Professor
Christopher Roy, Lecturer
David Beratan, R.J. Reynolds Professor of Chemistry
Katherine Franz, Associate Professor of Chemistry
Kenneth Lyle, Instructor
Robert Harris, Teaching Assistant

At the beginning of each unit, students were responsible for reviewing the resources associated with that unit's learning objectives via the course management system, Sakai.[1] The resources came from a variety of sources, matched to learning objectives. Resources included a brief video introduction by Dr. Craig, PDF/ePub documents (often created from websites), specific segments of videotaped lectures (for example, from MIT's OpenCourseWare), links to websites, brief whiteboard or prepared presentations by members of the Duke project team, and video demonstrations (from Khan Academy or created by the Duke project team). In addition, some units contained sample problems for students to test themselves. Almost all of the material was compatible with a variety of electronic devices. (*See screen shot, Figure 1, below*.)

Figure 1 - Sample Unit on Acids and Bases as viewed in Sakai



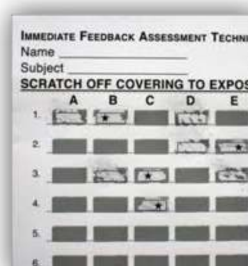


Figure 2 – In TBL, "IF-AT" forms can be used for team quizzes

In the first class of a unit, students were given a multiple choice quiz upon arrival to assess their understanding based on their advance preparation. Student teams re-took the same quiz, but this time collaboratively. Each team received immediate feedback on whether they had the correct answer by using IF-AT forms (*Figure 2, right*). If incorrect in their first attempt, the team could answer again (for a reduced number of points).[2] Dr. Craig would then respond to questions and

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[1] Fall 2011 was the first semester that Sakai's learning management system was in production at Duke, and most faculty had yet to adopt this platform for their course web sites. This factor did not appear to impact the students' course experience.

[2] See, "How does IF-AT work?", http://www.epsteineducation.com/home/about/how.aspx

comments. The remainder of the class was generally devoted to students working problems as a team, with Dr. Craig and the Teaching Assistant, Robert Harris, circulating between the groups, coaching and listening for problems. Occasionally, Dr. Craig would pause these discussions and provide a general explanation but was not observed to "lecture" for more than 5 minutes during a class session. In some class meetings, Dr. Lyle provided demonstrations of chemical principles (as he does for many chemistry courses at Duke). Students periodically reviewed each other's contributions to the team using the peer review criteria they had discussed on the first day of class.

Students were assessed individually on three midterms and a final exam, in problem-solving format. The first midterm was identical in the traditional and alternative sections; more than half the questions were identical between course sections in the subsequent midterms .

Assessment of the project

The outcomes of the course redesign project and the lessons learned were assessed using a variety of data sources:

- A survey of students in the redesigned section of Chem 43 (n=15, response rate = 52%), including quantitative data and open-ended comments
- 9 class session observations by an academic technologist
- Comments from the instructor, including a structured interview completed after the semester
- Average test scores from the redesigned section and the traditionally taught section
- Data from end of course evaluation administered by the Office of Assessment, and registration data for the next semester

Human subjects approval for the assessment was received from Duke's Institutional Review board. Course evaluation data was released by the instructor after the end of the semester. The instructor was not involved in the assessment of the project during the semester, and no information about the assessment was provided to the instructor until after the end of the semester.

In addition, Professor Ruth Day examined student knowledge structures in the team-based learning section, as part of a study on the nature of knowledge structures across disciplines and the impact of different teaching methods.

Findings

Nearly all aspects of this new course format are evolving, so these findings are only a preliminary assessment of the first iteration of a multi-semester process of redesigning this and other similar courses. Since Dr. Craig had not previously taught a course using any of these techniques, we expect that subsequent iterations may yield more dramatic results as Dr. Craig shapes and adapts future courses. The results are grouped below in four categories based on the most significant instructional changes: the two aspects of team-based learning as an alternative to traditional lecture-based teaching, namely students learning the basic material before class, and class time devoted to team-based problem solving; the use of e-resources; and student use of iPads.

1. Eliminating lecture-based content delivery during class time in favor of student pre-class preparation

- Students were offered the opportunity to transfer seamlessly to the concurrent traditional, lecture-based section at any time. All students elected to continue in the alternate section.
- On three midterm exams, students in both sections answered many of the same questions. The student performance on these questions was identical between the sections (*Figure 3, right*)
- Dr. Craig concluded that students did not need a lecture to learn the material, as students did just as well as the other section.

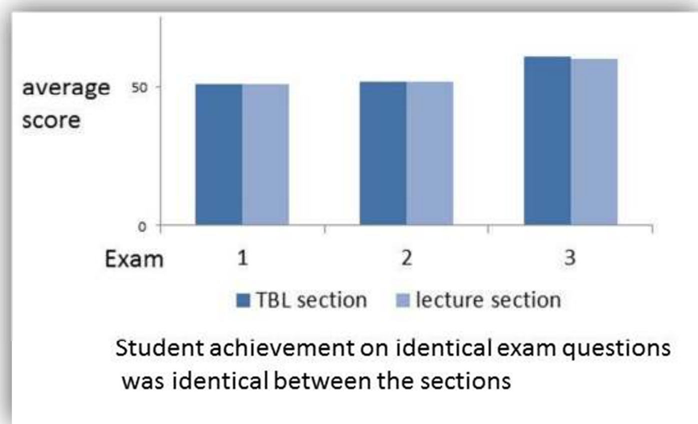

Figure 3 - Comparison of exam scores between experimental and traditional sections

- Replacing the required discussion sessions with optional office hours did not negatively impact student learning outcomes.
- Selecting, preparing, and in some cases, generating content was time-consuming for the teaching staff.

Students were asked to comment on team-based learning, and one comment addressed the need to be prepared.

> *"While team based learning was good, I found it hard to be completely ready with all the material in order to take a quiz at the beginning of class."*

Only one student commented that s/he would have preferred the lectures. In contrast, another student pointed out that:

"In my case, team-based learning was very productive and efficient due to the camaraderie between the members in our efforts to help each member work to their fullest abilities. This meant that you needed to show up to class every time, as each member was influential to the day-to-day discussions and problem sets. Also, team-based learning led to a better acquisition of the material. Whereas in a normal lecture-based section, if you didn't understand part of the material, you might shrug it off until the test as it takes much effort to work on your own to understand it. However, in our team-based learning, there was a sense that your team members will help you any time you don't understand something, and this learning was more immediate, less complex, and was able to provide me a fuller overall understanding for much of the material."

The results indicate that students will learn prior to class if the course is appropriately structured, and should alleviate faculty concerns that students cannot or will not prepare for class in which they will be active instead of lecturing.

2. Using course time to engage students in active problem solving and discussion in a team-based learning format

- Dr. Craig learned from listening to the students that "The students aren't necessarily thinking what I think they are thinking"
- Dr. Craig observed that, despite the course meeting at 8:30 in the morning, attendance was generally over 90%, which he had not seen in lecture-based courses, much less 8:30 in the morning.
- Students were offered the opportunity to transfer to the traditional section upon request any time. No students transferred.
- The majority of students (10/15 survey respondents) said that they would take another course taught using team-based learning.
- Student opinions about whether team-based learning positively impacted their learning were mixed. 8/15 felt they were learning as much in team-based learning as they would in a traditional lecture-taught course.
- A higher proportion of students from the team-based learning section registered for Organic Chemistry the next semester (*Figure 4, right*)
- Preliminary results from Professor Day's work showed that students' knowledge became more structured when they worked in teams than when they worked individually. Instead of perceiving loose connections among course concepts, the teams understood them as part of a more coherent overall pattern.

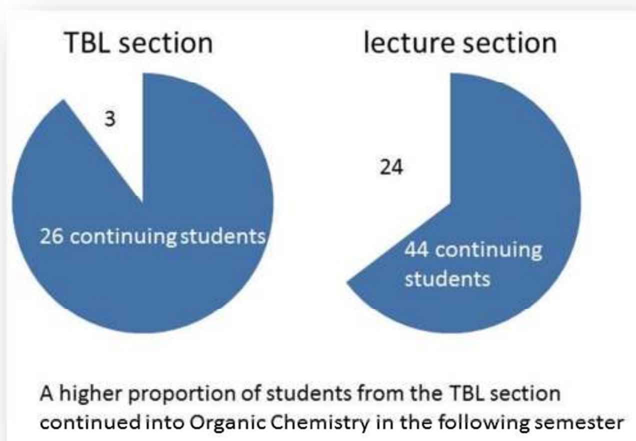

Figure 4 - Initially, a greater proportion of the TBL students continued into the subsequent course, Organic Chemistry.

- On the course evaluation (27 students responded), the course overall quality was ranked 4.16 out of 5.
- The quality of instruction on the course evaluation was ranked 4.54 out of 5.
- On the course evaluation, students in the team-based learning section ranked “learning to analyze ideas, arguments and point of view” more highly than students in the concurrent section did.

It may be significant that students did not object to using classroom time for active learning rather than lecturing, given the population of students. These students have been very successful in traditional lecture-based classrooms and are achievement-oriented; many plan to attend medical school. Their willingness to try team-based learning, and the fact that no student transferred out of this class into the more traditional class (which met at the same time) is a strong positive result in favor of team-based learning.

Some students did find some problems with in class problem-solving. One student commented, “I like the idea of team-based learning, but in practice isn't necessarily helpful at all times. When we do the group problems, our team is always rushed and the focus is on getting the right answer to turn in. This is nothing against the members of my group, but sometimes there is simply not enough time to thoroughly go through a problem so at the end of class I often walk away still confused or unable to do a problem.” Dr. Craig intends to modify the in-class problems in the next iteration of the course.

Dr. Craig noted that often professors construct exam questions that require that students to integrate and apply knowledge, but then observe that students don’t like this kind of question. In the team-based learning class, Dr. Craig found, “Students love this kind of question, but much, much more when they get it in a situation that allows them to be thoughtful." He hopes to expand the use of this kind of question in class.

When asked about their interest in the alternative section, many students cited the reputation of the instructor, and their positive impression of him persisted throughout the term. As one student noted, “Dr. Craig makes this class what it is, not the learning method.”

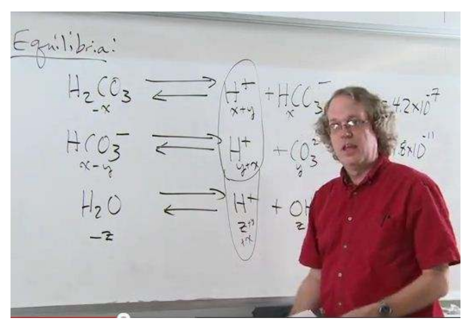

Figure 5 - Worked problem-solving video featuring Duke chemistry faculty member Richard MacPhail

3. Use of a series of open educational resources instead of a textbook

- Selecting, reviewing, creating and editing videos and other e-resources for Chem 43 represented the largest and most significant area of effort for the course redesign (over 600 individual resources were used)
- Nearly all student respondents to the survey reported consulting the print textbook in addition to the online course content (14/15 survey respondents).

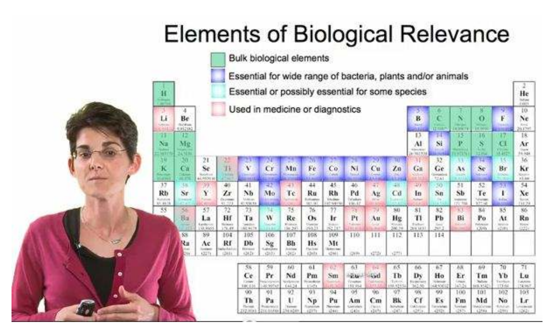

Figure 6 - Lecture video featuring Duke chemistry faculty member Katherine Frantz

- Students reported using most or all of the e-resources assigned for the class (11/15 survey respondents)
- Regardless of the device used to access course content, most students reported rarely or never encountering technical problems (11/15 survey respondents).

Among all course materials provided, students preferred text and images, and videos of problems solved (*Figure 7, right*)

- Only 20% of the students (3/15 survey respondents) would recommend that other classes be taught with online materials rather than a text.

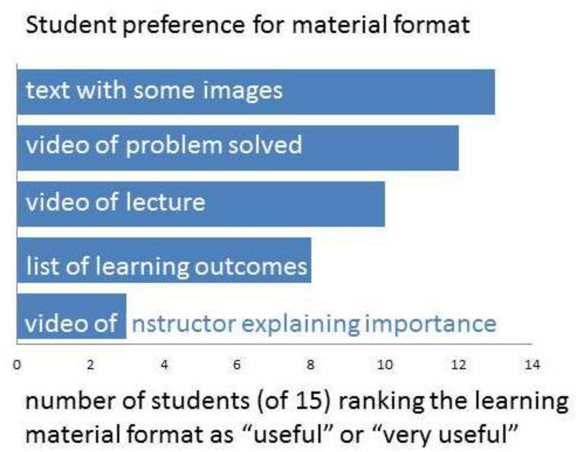

Figure 7 - Student preference for material format

In the survey, students were asked "Why did you consult a chemistry textbook"? Thirteen students replied. Six appreciated the organization of textbook, mentioning the flow, outline and completeness. The electronic learning resources selected for the course came from a variety of different sources, and therefore did not have the narrative flow and consistent presentation generally found in a textbook. Further, these students have been academically very successful in traditional learning environments, involving textbooks and lectures. Therefore, the students are accustomed to studying from a textbook format. About the textbook, students commented:

> *"The flow of the textbook was easier to follow, especially for many of the more challenging units. It ended up being useful because I could get the more general ideas from the textbook, then look at the online PDFs/videos to add more details to what I read and solidify my understanding."*

> *"Sometimes I was frustrated with the layout of the online units because the concepts did not always flow, so I would use the textbook to get an overall plan, then refer to online materials in the order that they came in the book."*

Five students said they used the text to access to practice problems. These practice problems resembled those on the exams (the exams were identical to those given in the other section that did use the textbook). As the course progressed, the professor provided more practice problems for the students, which may have replaced the text for some students.

> *"Until Dr. Craig posted the book problems on Sakai that went along with the individual chapters, I needed the textbook in order to work out practice problems (with verified answers*

from the solutions manual) in preparation for the test. After he posted these questions, a textbook was no longer needed, but a solutions manual was."

Dr. Craig pointed out that using a collection of educational resources is a good fit for General Chemistry because this course is more like a collection of short stories than a novel. In other words, aggregating multiple resources would work for some courses, but not for others. He also felt that an online homework system for the students to test themselves would be a good addition.
Two students commented that when reading, the pacing is under student control, compared to a video, where it is more difficult to focus in on the needed explanation and skim the other materials. As one student explained:

"Reading the textbook, which delivers the information in much more detail, has allowed me to learn the material at whatever pace I'm comfortable with. There's also an added benefit to learning the information from pictures, text, and problems on a page in addition to hearing the online lectures, and doing the numerous practice problems have also been helpful in solidifying my understanding of each unit."

In future courses that replace a text with a series of resources, students would benefit from a more consistent flow of the materials, additional practice problems and resources delivered as text and images rather than video. As one student commented,

"I do recommend that classes be taught with online materials, including texts, videos, and so forth, but the teacher should also include an explicit list of what the student is expected to learn. We had 'Learning Objectives', but they were occasionally vague, and getting high marks on a test required that we go beyond the objectives. If the objectives are constructed so that a student may individually ascertain that s/he knows all that needs to be known, the online material system has my full confidence behind it."

2. Students using iPads to access course materials

- Although iPads were made available to all students in the class, a majority of students (9/15 survey respondents) preferred to use laptops to access the online course content.
- Four (of 15 survey respondents) said they did not try using the iPad for the class.
- A slight majority of survey respondents (8 /14) reported using an iPad to access course content. These students **also** used a PC (n=5) or Mac laptop (n=3) to access course content.
- Fewer than half the students (6 of 14 survey respondents) reported that the iPad was useful or very useful for the class.
- Among the eight iPad users, most felt the iPad was useful (n=7) and easy to use to access course content (n=7).

- A majority of students (64%) reported that having an iPad did **not** make them more likely to use the electronic course materials.
- Only 1 of 15 survey respondents students surveyed had their own iPad.

These results may indicate that students in this class have different levels of comfort with technology. Some students found the iPad useful, and others would prefer to continue to using techniques (including the textbook) that have worked for them in the past.

The instructor experience

Dr. Craig concluded that team-based learning is a success. He found that lecture was not necessary for student learning, and in listening to the students solve problems, he learned that students aren't necessarily thinking what he thinks they are thinking. He speculated that some of the frustration expressed by faculty and students on student performance on exams in many courses is because the students do not get practice on the types of questions faculty expect them to be able to solve in a traditional course. He expects that the next iteration of team-based learning will be much more successful, and emphasized that there are many things he would like to do differently. The student experience was positive, the evaluations are reasonable, and he enjoyed the interactions with and between students.

Conclusions

The team-based learning format, which included both students learning material before class instead of lecture, and active, team problem solving in class, was effective in this course. Students learned the material (as evidenced by identical exam scores between this section and the lecture-based section), and liked the format (most students would take another team-based learning course, and most felt they learned as much or more from team-based learning compared to a traditional course).

The iPads were useful for some students, while others used other methods to access course materials, reflecting that students are individuals, with a variety of attitudes and experiences with technology.

In this course, electronic resources did not replace a textbook for most students, since most consulted a text regularly. The students reported needing the text for narrative flow, for additional practice problems and to control the pacing. Students did use the materials, indicating that the textbook alone was not sufficient. These results suggest that future use of online resources to replace the text should take into account the flow of materials, provide practice and should not rely solely on video.

Of the three interventions in this course (e-resources instead of a textbook, iPads to access course material, and team-based learning course design), team-based learning emerged as the most effective, both in terms of learning and student favorable opinions.

Limitations of these findings

These findings should be treated as preliminary for a variety of reasons. Students eligible for honors chemistry are historically high achievers with strong preparation in chemistry, and so these students are not necessarily representative of an average Duke student. Although the students in the experimental and traditional sections had the same rigorous level of academic preparation (all were qualified for honors chemistry), students who self-selected to participate in the experimental section may have been more interested in or open to active learning approaches. However, this potential source of bias could also have adversely impacted the experimental section; high achieving students who have succeeded in traditional science courses and are eager to achieve top grades may be less open to experimental approaches.

Half of the students enrolled in the course responded to the survey, so the survey results may not give a complete picture of student response. Multiple attempts to engage significant numbers of students in focus groups to supplement and confirm the survey findings were unsuccessful.

Finally, this course was the first time that Dr. Craig used team-based learning, e-resources and iPads. The combination of the small course size with the fact that several interventions were introduced at once makes it impossible to conclusively attribute project outcomes to any particular factor. More conclusively positive results are possible in future semesters now that the instructor has more experience with these new approaches and will be adjusting his courses based on these experiences.

Future Directions

Dr. Craig will be using team-based learning again in fall 2012 in a larger course co-taught with a colleague. If this course is also effective, the department plans to increase the number of team-based learning courses. Dr. Craig expects to modify and expand the in-class problems, and he intends to expand team-based learning into the laboratory part of the course.

Our assessment will follow the student cohorts as they progress through future courses. We intend to look at more long-range outcomes, such as student performance in future courses and student persistence in science majors for students in the team-based learning section compared with the traditional section.

Opportunities for Academic Technology

Team-based learning requires extensive record-keeping and administration, which would create significant challenges for larger courses. Faculty need technology tools to facilitate the administrative aspects of team-based learning. Specifically, faculty need tools to automate peer assessment, group grading on quizzes and assignments and the administration of immediate feedback tests. Also, they need the flexibility to include all aspects of team-based learning in assessing students. Six specific recommendations for academic technology surfaced:

1. Student group quizzes should be online with immediate feedback on each question, including the ability to select a second and third answer with a decrement in the final score based on number of selections before students select the correct answer.

2. Team quiz grades must be distributed to each individual automatically.

3. Team grades on projects must be distributed to each individual on the team automatically.

4. Periodic peer assessments must be collected from each student for the other students on the team, and then feedback delivered to the assessed student.

5. Peer assessment scores must be calculated and distributed to the students, including the ability for the professor to implement a customized scale for weighting peer assessment.

6. Individual grades, team grades, exam grades, team project grades and peer assessment scores must all be available for inclusion in a final grade (based on a calculation supplied by the professor).

If a course is delivered using a variety of resources, there should be recommender system that the students can use for rating the usefulness of course resources, and learning analytics should be available to the professor for understanding which course resources are most effective.

Appendix 1. Text of email invitation to prospective students

We are writing to let you know that a second smaller section of CHEM 43L will be offered this fall in addition to the main section in which you are currently enrolled. The main section CHEM 43L.001 will be taught by Professor Michael Therien in a traditional lecture format, with an emphasis on problem solving skills. The course content is structured around a single textbook: “Chemical Principles” by Steven S. Zumdahl.

The second section CHEM 43L.002 will be taught by Professor Stephen Craig. While this section will also emphasize problem solving skills, the format of this section will be different from CHEM 43L.001. In lieu of a specific text, students will use multimedia to study basic concepts prior to class, and class time will be devoted to applying those concepts through a variety of interactive exercises.

Both sections will cover the same topics, as outlined in the course description, and we anticipate that the average workload (total hours/week) will be the same for the two sections (although spread differently through the semester). The lab component of the course will also be identical for the two sections.

Enrollment in the second section is limited, and students will be admitted on a first come, first-served basis. If you are interested in switching into CHEM 43L.002, please let us know. We can make the change in your ACES schedule for you as long as your schedule can accommodate any change in recitation time that may be required. The lecture times for both sections will be the same (TTh 8:30 – 9:45 AM), so the impact on remaining course schedule should be minimal for students who wish to switch into CHEM 43L.002.

Appendix 2. Sample unit outline for Molecular Orbital Theory

To see this outline with linked resources, Duke affiliates can go to:
https://sakai.duke.edu/portal/site/chemdemo

Introduction to Valence Bond Theory

Learning Objective (LO) 1. Describe how covalent bonding relates to the overlap or constructive interference of atomic orbitals, and to electron density between the bonded atoms

LO 2. Describe how bonds are formed in the "localized electron" or "Valence Bond" model by overlapping half-filled atomic orbitals on neighboring atoms, and draw pictures to illustrate this for simple cases like HF or F2

Formation of Sigma Bonds

LO 3. Sketch a typical graph illustrating how the energy of a diatomic molecule varies with the internuclear distance R, explain which interactions result in the minimum in energy and the sharp rise in energy at small R, and identify on the graph the molecular "equilibrium" bond length and dissociation energy

Hybrid Orbitals

LO 4. Describe the rationale for introducing atomic orbital hybridization, as well as the conceptual process involved in forming hybrid orbitals (e.g. electron promotion, hybridization, bonding and the balance of energy cost and gain)

LO 5. Sketch hybrid orbitals for sp, sp2, sp3, dsp3, and d2sp3, and describe the geometry of the hybrid orbitals around an atom for these cases (e.g., linear, tetrahedral, etc)

Molecular Geometry

LO 6. For a given molecule, be able to go from the Lewis structure, to the electron geometry, hybridization, and bond angles around each atom, to a sketch of the valence bonding orbitals for the entire molecule, including both sigma and pi bonds

LO 7. Use the sigma and pi bonding in a given molecular structure to deduce the overall geometry of the molecule, especially in cases involving multiple bonds (e.g. the planarity of ethane)

Molecular Orbital Theory

LO 8. Describe how approximate molecular orbitals in the MO approach are formed from linear combinations of atomic orbitals

LO 9. For diatomic molecules, be able to describe and sketch the sigma and pi bonding and anti-bonding orbitals that result from combinations of the s and p orbitals on the two atoms

LO 10. Use molecular orbital energy level diagrams to show how the electrons in a homonuclear diatomic molecule occupy the various molecular orbitals, and from this diagram determine the bond order, MO electron configuration, and the number of unpaired electron spins (hence paramagnetic vs diamagnetic); also be able to go from a MO electron configuration to MO diagram

LO 11. For a series of diatomic molecules, use bond orders to determine their relative stabilities, bond lengths, and bond energies

LO 12. Extend the use of molecular energy level diagrams described above to heteronuclear diatomic molecules and diatomic molecular ions

Delocalized Bonding

LO 13. Describe how the molecular orbital approach can describe delocalized bonding, for example in hydrocarbons with conjugated pi systems, and thereby explain the averaging associated with resonance structures in the Lewis model of bonding

LO 14. Relate molecular orbital descriptions of bonding to classical descriptions of covalent, polar covalent, and ionic bonds.

Appendix 3.Grade Breakdown for Team-Based Learning Course

The ranges in parentheses were guidelines provided by the professor to the class. The numbers in the right column reflect the class grading policy, negotiated among the students. The laboratory grade counted for 20% and was not negotiable.

Class activities (20-60%)	
Individual quizzes (5–15%)	5%
Team quizzes (5–15%)	15%
Team activities/projects (5–15%)	15%
Peer evaluations (5–15%)	15%
Exams (20-60%)	
Midterm 1 (5–15%)	5%
Midterm 2 (5–15%)	10%
Midterm 3 (5–15%)	10%
Final Exam (5–15%)	5%