

Chemistry and Education: Instructional and Assessment Strategies to Improve Knowledge Retention

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Abstract

The purpose of this research project was to analyze the General Chemistry course sequence for Majors at Spelman College that has been revised using a semi-self paced, blended format that incorporates innovative instructional and assessment strategies. Quantitative and qualitative data were analyzed to determine the impact on concept mastery and student knowledge retention. Instructional strategies involved online content delivery, freeing class time for team-based activities such as Process Oriented Guided Inquiry Learning (POGIL) worksheets, case studies, and problem-solving sessions. Concept mastery was measured through “gated” chapter tests, which allow students multiple attempts at passing a test with a score of 85 or better. Knowledge retention was measured based on the standardized ACS General Chemistry First Term and Full Year exams given at the end of each fall and spring semester, respectively. The fall semester average final exam test scores increased from 39.1 (out of a maximum of 70 points) averaged over the 3-year period of 2010-2012 to an average score of 44.1 in fall 2013 for the majors-only course. The spring semester cumulative final exam average test scores increased from 34.8 averaged over the 2011 and 2012 spring semesters to 42.8 in spring 2013. Over the four academic years 2010-2014, the fall semester average ACS final exam test scores for the majors-only course (CHE 111) increased by 30.3%, on average, as compared to the final exam scores earned by other science/pre-health concentration students enrolled in other sections of the same course. On average, the spring semester cumulative ACS final exam average test scores for the majors CHE 112 course increased by 26.6%, as compared to the other sections. Qualitative measures of student attitudes and perceptions were also obtained using a Qualtrics survey, which was sent to all students who had enrolled in the majors-only courses. The data from the survey showed how students felt about the gated test system. Many students agreed that the gated test system was effective when developing concept mastery.

Keywords: Chemical Education, Blended Course, ACS Exam, and ANOVA

1. Introduction

Educators are continually searching for innovative pedagogies as they seek to improve student learning outcomes in their courses. With the advent of new and improved technologies, the blended or “flipped” classroom has come to the fore as a best practice in education¹. The blended course promotes maximal learning by placing the realm of content delivery online and allowing classroom sessions to focus on deeper learning through the use of student-centered activities. This pedagogy offers students the flexibility to learn concepts at their own pace away from the classroom, allowing for class time to focus on student-centered activities that promote deeper learning (i.e., IBL, case studies, team-based learning). This idea of the “semi self-paced course” combines some of the best aspects of student regulated learning². For example, the Keller plan³, which has been used in Physics classes for decades, provides students with material that they must master on their own with little to no formal instruction involved.

Students are allowed to take tests multiple times in order to pass and move onto the next topic. The number of tests successfully passed dictates the final grade in this self-paced course. The semi self-paced course requires that most course content be provided to students for them to review outside of class. Face-to-face classroom time, however, is still maintained. Unlike courses taught using the traditional lecture format, classroom sessions now focus on student-centered learning activities. Subject mastery is promoted and assessed through a variety of strategies, many of which utilize new educational technologies such as iPad apps, personal response (“clicker”) assessments, online homework and adaptive learning systems, and multiple testing. It is when course content, classroom sessions, and assessment tools are integrated thoughtfully that the blended course promotes self-regulation of learning and subject mastery.

Many of these instructional strategies are currently being incorporated into introductory science courses at Spelman College, a four-year liberal arts Historically Black College for women. This specific research focuses on the CHE 111/112 General Chemistry course sequence, which is a service course enrolled by First Year Chemistry and Biochemistry majors, sophomore Biology majors, and other students enrolled in majors with the pre-health professional track. In 2009, the Department of Chemistry decided to form a section of this course sequence in which all of the First Year students are required to enroll. The reason for forming this section was that the department wanted the majors to experience the curriculum as a cohort. The General Chemistry for Majors sequence is not exclusive; anywhere from 10-25% of the class is comprised of other science or pre-health majors. It also covers the same material and uses the same textbook as the other two sections of CHE 111/112 that are taught using a traditional lecture format. In addition, all course sections take a common final exam. The majors’ courses were revised to incorporate inquiry-based learning strategies and to promote team-based learning. The “gate” system of testing was also introduced back in 2009 where, as with the Keller system, students are allowed to take topic tests multiple times in order to master the material. As of the 2012-13 academic year, the course sequence was revised yet again to incorporate an innovative blended semi self-paced course learning strategy. The semi self-paced format has combined online lectures, continuously available to students through the college’s course management system, with face-to-face team-based learning activities. This pedagogical strategy has been developed to allow each student to move at her own pace (to some extent) through the coursework and to focus on improving comprehension of topics that are challenging to her specifically. These activities combined with the use of online homework/adaptive learning systems promote iterative learning, self-assessment, knowledge retention, and subject mastery.

The purpose of this research has been to assess the success of the instructional format used in the General Chemistry for Majors course sequence. To determine the impact of these techniques on student subject mastery and knowledge retention, data was obtained from the standardized American Chemical Society General Chemistry exams (First Term and Full Year), which all students enrolled in the three General Chemistry sections take as the common final exam at the end of each term. In addition, surveys were created and distributed to the chemistry majors in the sophomore, junior, and senior classes in order to gather qualitative information regarding student perceptions of the gate system.

2. Methodology

To assist students in the blended semi-self paced course with concept mastery and knowledge retention, the students are provided with pre-, in-, and post-class activities. Together these activities provide the students with course material and allow the students several opportunities to view all of the conceptual material being taught throughout a particular semester. Pre-class activities include online lecture slides also known as LOL’s (Lectures OnLine.) These online lectures are narrated by the instructor and range from 10-20 minutes in length. Another component of the pre-class activities is textbook reading assignments. In collaboration with the LOL’s, Puzzles Or Problem-solving Sessions (IPOPS) are based on the lectures online that are posted on the College’s course management system (Moodle). On average, three IPOPS were used per chapter during the fall semester and about four times per chapter during the spring semester.

In-class activities, for the four days a week that students meet for 50 minutes, include students working in teams to review material, with the instructor randomly calling on teams to respond to questions. Students are also encouraged to ask questions during Q & A sessions in order to make certain that they clarify any problems they have with the material. Typically, 1-2 Process Oriented Guided Inquiry Learning (POGIL) worksheets are used per chapter to analyze how students are comprehending concepts. POGIL worksheets are used in the classroom to provide students with the opportunity to think critically and analytically as well as to better process the content being delivered. During classroom sessions, students work together to answer questions that will lead them to

formulate their own conclusions. It is the job of the instructor to observe the teams as they work and be available to address questions or concerns presented by the class. In the fall of the 2013-2014 academic year there were eight chapters covered and on average there was one POGIL worksheet per chapter. In the spring of that same academic year, there were nine chapters covered with an average of two POGIL worksheets per chapter. Case studies are also used to analyze student comprehension and promote analysis skills. Case studies are scenarios that teach process skills and critical thinking and involve team-based discussions and analysis. Unlike POGIL worksheets and IPOPS, case studies are not used as much during this academic year with two cases used each semester.

The post-class activities consist of online homework and learning environments. Over the past four academic years different online homework programs have been used, such as ChemSkill Builder by McGraw-Hill Education and Mastering Chemistry by Pearson, which provides both online homework and conceptual tutorials. Currently the Connect/ LearnSmart system, also by McGraw-Hill Education, is being used, which provides the two academic elements of a digital teaching/learning environment and adaptive learning. All of the systems used allowed for questions to be randomized so that no two students were assigned the same set of problems. The online adaptive learning system, LearnSmart, also allows students to assess their prior knowledge on a given topic in order to focus their attention on those topics where they did not have a clear understanding. Another method used to study knowledge retention was the “Brain Dump.” Students are given a chemical system and asked to write important facts regarding the system based on their knowledge up to that time. In this way, students could connect ideas across chapters or even semesters and see how their chemical knowledge is cumulative over time.

As a summative assessment, the American Chemical Society (ACS) 2002 General Chemistry First Term Gray Form was used for all three CHE 111 course sections in each fall semester over the time period discussed and the ACS 2003 Full Term Standardized Test Gray Form was used as the comprehensive full-year final exam for the three CHE 112 course sections during the spring semesters. In this way, the majors’ course could be compared to the other course sections in terms of comprehension and knowledge retention. Table 1 below displays the various pedagogical methods used in the semi-self paced general chemistry since 2009.

Table 1: Pedagogical Methods Used Over The Past Four Years

Pedagogical methods	Academic Year 2010-2011	Academic Year 2010-2011	Academic Year 2012-2013	Academic Year 2013-2014
POGIL Worksheets	X		X	X
Narrated Online Lectures			X	X
Sample Gates			X	X
Gates	X	X	X	X
Online Homework	X		X	X
Adaptive Learning System				X
Required Notebook			X	X

3. Data Analysis

To properly analyze the data presented in this paper, ANOVA (ANalysis Of VAriance) Statistical Software was used to show the statistical correlations of the past three academic years. All of the academic years from 2010 to 2014, were analyzed using the ANOVA software. Qualtrics Online Survey Software was used to develop and administer a survey focused on the effectiveness of the gated test system. The Qualtrics survey was created to gain a student perspective of the gated test system and the semi-self paced teaching method. The survey consisted of 13 questions, eleven multiple choice and two comment based questions. The survey was sent to all of the current chemistry and biochemistry majors at Spelman College. The American Chemical Society (ACS) 2002 General Chemistry First Term (fall semesters) and ACS 2003 Full Term (spring semesters) Standardized Test (gray form) was used as the final exam for the CHE 111/112 courses, both traditionally taught sections and that taught using the semi-self paced format. The raw scores from the final exam (out of 70 questions) as well as the ANOVA data can be viewed in the results section. Table 2 is a list of the questions formulated and asked in the Qualtrics survey.

Table 2: Qualtrics Survey Questions

1. What is your current classification?
2. What chemistry track are you taking?
3. Select the range that your current GPA falls into.
4. If you have attended the CHE 111-112 General Chemistry for majors course sequence where gated tests were used, please answer questions 5 through 8.
5. Rate your agreement with each statement. The gated test system took the pressure off of doing well on a test, since I had more than one chance to pass. The days and times gates were offered were convenient. More days and times should be available for taking the gates. I would have liked the gates to have been offered online (e.g., through moodle). I would have liked to have been able to take a gate at any time. The gated tests were difficult.
6. Rate the following items about the gated test system. I studied hard in preparing for the first time I took a gate for a given chapter. When studying for the gate, I reviewed gates that I did not pass prior to taking it again. The chapter in the textbook was useful to me when preparing for a gate. The powerpoint slides on the WebCT/Moodle course site were useful to me when preparing for a gate. My classmates were useful to me when preparing for a gate. The tutors were useful to me when preparing for a gate. My instructor was useful to me when preparing for a gate.
7. Rate the following items about the gated test system. The gated tests covered basic concepts for a given chapter. It was easy to fall behind in my classwork because of having to study for the gates. The gated test should have covered more than one chapter. I feel that I retained the information better over time because of the gated test system. I feel that I was better prepared for the final exam having participated in the gated test system. I feel that I received a higher grade in the class having participated in the gated test system. I think the gated test system should not used in general chemistry.
8. Which of the statements below would you most likely agree with?
9. Answer the following questions about online lectures in your General Chemistry and Organic Chemistry lecture courses. My class had online lectures for each chapter made available on Moodle. The online lectures on Moodle were useful when preparing for a gate/test. I would like to have more online lectures available. The POGIL worksheets/ ChemDrills were useful in preparing for a gate/test. Clicker quizzes let me know what concepts I did not understand.
10. Answer the following questions about sample gates. My class had sample gates for each chapter made available on Moodle.

I reviewed the sample gate before taking the actual test.
The availability of a sample gate for each chapter has or would have helped me better prepare.
11. I typically passed the gate by the: (choose the best response)
12. The passing grade for the gate should be?
13. After a chapter is completed in class. How long should the gate be offered for that chapter?
14. How beneficial is the gated test system? Explain why.
15. How beneficial are online lectures? Explain why.

From the above questions, four questions were chosen to see on average how students felt about the gated test system and the blended semi-self paced method. Table 3 displays those questions as well as the average student response and the standard deviation.

Table 3: Selected Questions: Qualtrics Survey Results

Question	Mean	Standard Deviation
The gated test system took the pressure off of doing well on a test, since I had more than one chance to pass.	1.87	1.13
When studying for the gate, I reviewed gates that I did not pass prior to taking it again.	1.37	0.52
I feel that I retained the information better over time because of the gated test system.	1.62	1.06
I feel that I was better prepared for the final exam having participated in the gated test system	2.37	1.51

*Based on 1=strongly agree, 2=agree, 3=neutral, 4=disagree, 5=strongly disagree; N = 8 respondents

The data in Table 3 shows that for questions 1-3 the averages were between strongly agreeing and agreeing with the statements. Question 4 displays an average of 2.37, which is between agreeing and being neutral to the question stated. This was interesting to discover because the data in figures 1 and 2 show that the students in the blended semi-self paced class have continuously scored higher on the ACS final exam as compared to the other two general chemistry classes, in both the fall and spring semester. However, since only 8 students responded to the survey, the statistical results are not truly valid.

4. Results

The following figures compare the semi-self paced general chemistry course with the two traditional lecture general chemistry courses. Figure 1 shows the results of the gated test system as well as ACS final exam scores from the spring semester, specifically for the semi-self paced course. The graph shows an increase in both the gates and the ACS final exam scores since spring of 2011.

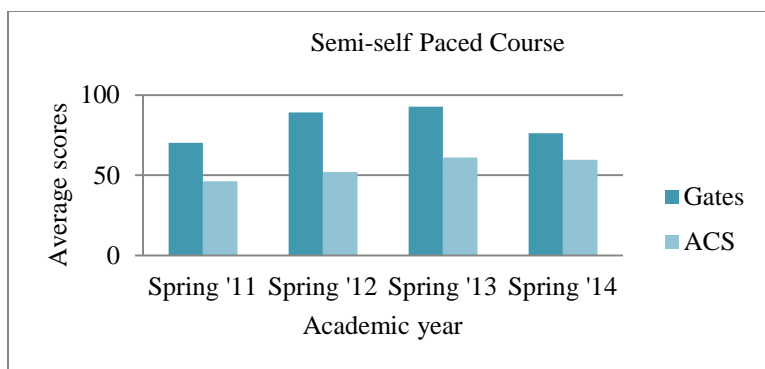


Figure 1: % Average Gate and General Chemistry ACS Full Year Final Exam Scores in the Blended Semi-self Paced Course

Figure 2 shows the average scores students received on the ACS final exam in all three general chemistry sections. Sections 1 and 2 are traditional lecture courses while section 3 is the semi-self paced course. Academic year 2010-2011 sections 2 and 3 were taught by the same instructor, the only difference between the two sections was the assessment technique used. The section 2 assessment technique was the usual chapter exams, while section 3 used the gated test system. The 2011-2012 academic year had some changes that occurred. The gated test system was only used in the fall of 2011. As shown in figure 2, the scores in the spring decreased compared to the scores in the fall for section 3. Due to the instructor being on sabbatical during this academic year, only the fall semester was taught using the gated test system. During the spring semester the students were taught using a traditional lecture format.

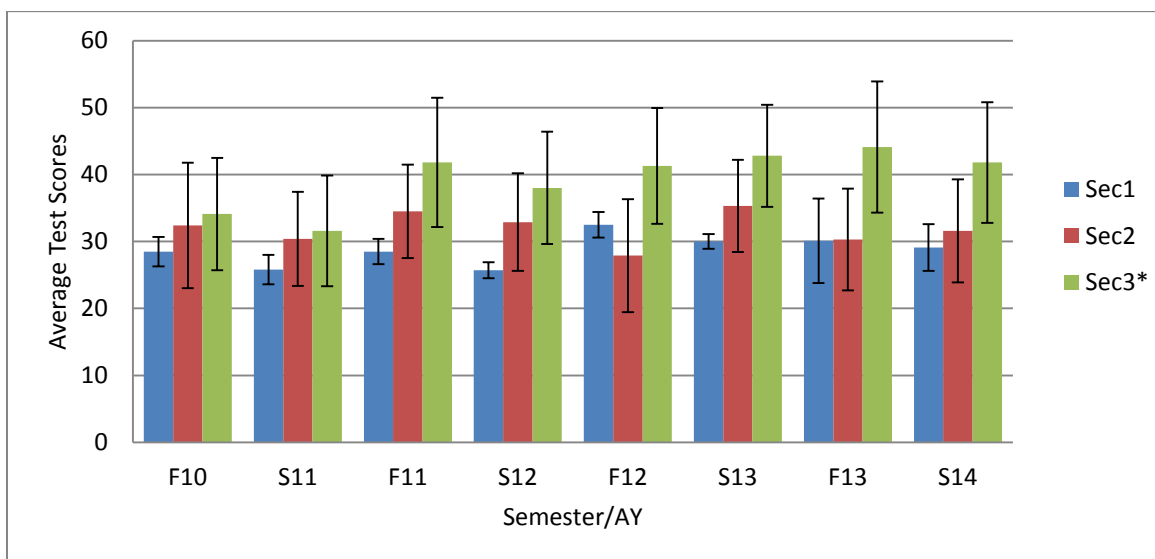


Figure 2: ACS Standardized General Chemistry First Term (Fall) and Full Year (Spring) Test Scores – all sections

Note: section 3* is the semi-self paced general chemistry course. (AY) stands for academic year.

Figure 3 shows how academic years 2010, 2011, 2013, and 2014 statistically compare.

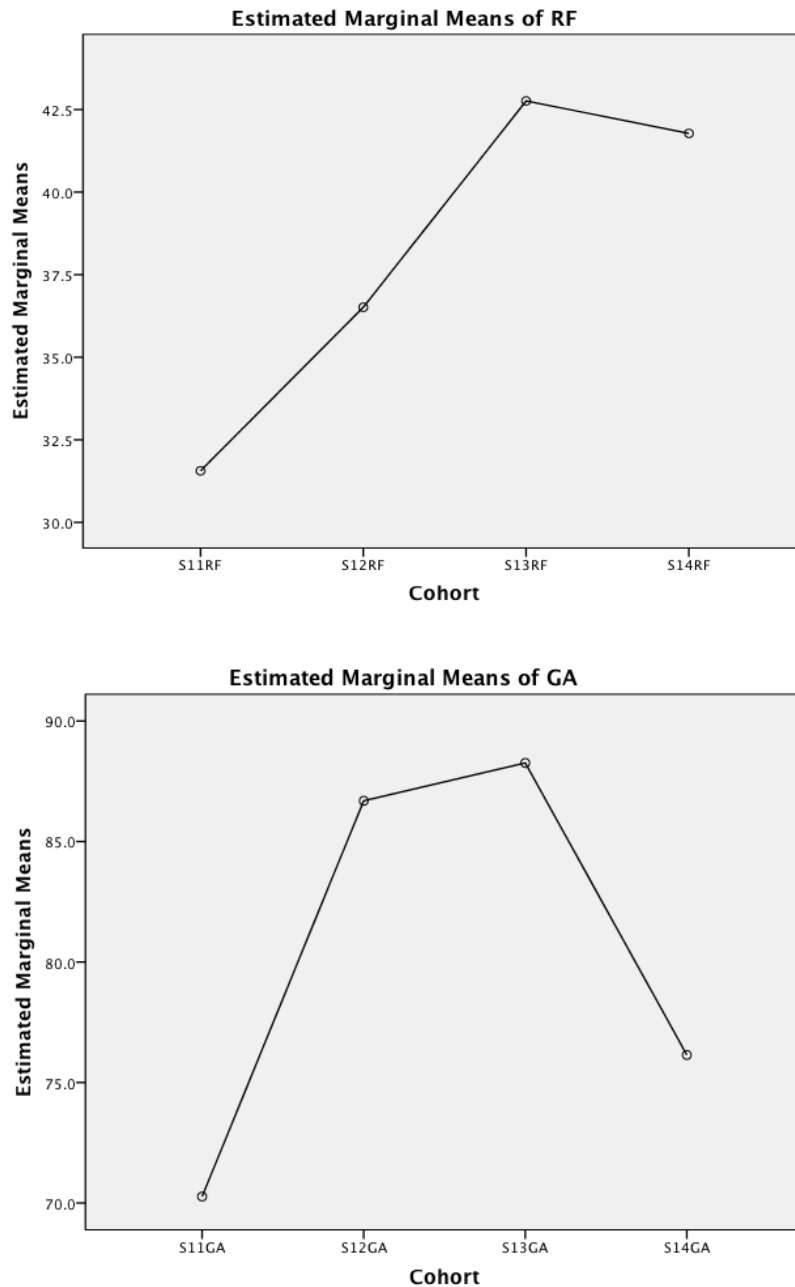


Figure 3: Raw Final and Gated test Profile Plots - Past Four Academic Years (ANOVA)

The ANOVA data shows that there is a significant difference between the four academic years in relation to the raw final scores ($p=.000$, with $p<0.05$ being significant to a 95% confidence level). Pairwise comparison indicates that there is significant difference between S11/S12, S11/S13, S11/S14, S12/S13, but there is no significant difference between S12/S14 or S13/S14 raw final scores. The same hold true for the gated test. The pairwise comparison indicates that there is significant difference between S11/S12, S11/S13, and S12/S14, S13/S14, but there is no significant difference between S11/S14 or S12/S13 Gates average scores.

5. Discussion

The blended semi-self paced method was introduced to promote independent student learning along with instructional assistance. The data above shows that from 2011 to 2013, the blended semi-self paced general chemistry course has been beneficial to student knowledge retention and subject mastery. As a part of the Qualtrics survey, students were asked two comment based questions that inquired about the gated test and online lectures (Refer to Qualtrics questions). Some of the student responses are as follows. One student commented on online lectures stating “To me [online lectures] were a good refresher of the actual lecture and made it easier to fill in the blanks in my notes.” This comment was made by a student who took the blended course in the fall of 2010 and the spring of 2011. As shown in table 1, during the 2010-2011 academic year, there was a limited amount of student support resources used. The student support resources that were used in that academic year were not as efficient as those being used currently.

The purpose of creating the Qualtrics survey was to give students the opportunity to express their opinions on how they felt the blended semi-self paced course and the gated test were affecting their academic performance. The survey was originally sent out to all of the chemistry, biochemistry, and dual degree majors at Spelman College. The students were given a week to complete and submit the survey. In table 3, it shows that the number of students that completed the survey was 8. While statistically insignificant, this information was still used and included because it does give information on how students feel about the gated test. Having more students respond to the survey would have been ideal. The data shown in table 3 may not have been a major contributing factor as far as student opinion goes but the data in table 3 does present an idea of what the advantages and disadvantages are to using the gated test system. A revised survey has since been administered and this additional information supports the fact that many students do respond better to the gated test than having a tradition exam. Not only does the gated test give students the opportunity to take an exam up to four times, it also allows students the opportunity to understand concepts better.

One of the essential focal points of the blended semi-self paced course is the assessment technique. The gated test system is used to improve upon subject mastery, allowing the students several times to see how a concept can be delivered. The majority of students agreed that the gated test system helped prepare them for the final exams. One student said that “The gated test system was very beneficial. Being that the questions were different on each gate, it gave me the opportunity to review and understand concepts in various contexts. The gated test system was very challenging and psychologically stimulating.” Another student said that “in retrospect the gated test system was very useful in helping students to understand the concrete concepts necessary to succeed in the chemistry field. They were also useful in helping develop better study habits.” These comments support the data that has been recorded in figures 1 and 2.

With the implementation of new pedagogical methods, both the gate scores and ACS final exam scores increased from 2011 to 2013. [National ACS Mean for First Term Test = 41.73; Full Term Test = 41.03.] The ACS standardized test data show that there is a significant difference between the CHE 111/112 General Chemistry courses taught using the semi self-paced instructional format (section 3) as compared to those sections taught using a traditional lecture format. Average final exam test scores for the section 3 classes have increased by as much as 47% over the other two sections. This difference is even more pronounced for the CHE 112 course ACS final exam assessment and is an important indicator as that exam is comprehensive and measures knowledge retention from the first term course. The gates appear to also have a strong correlation to the ACS exam scores. The current academic year (2013-2014) has shown a decrease in both the gated test and ACS scores within the blended course. Although these results do not follow the trend shown in the previous academic years, these results are important to the success of the blended semi-self paced method. In comparison to the two traditional lecture courses, the students in the blended course continue to receive higher scores on the ACS final exam for both fall and spring semesters (Refer to figure 2). It is also important to note that, while utilizing the gates and POGIL worksheets have a significant impact on final exam scores as seen when comparing majors’ sections over time, the structured blended instructional strategies that incorporate the online lectures and problems have made a bigger impact on student scores.

It is also important to point out that the other course sections cannot be considered as true “control” cases as the student population differs from that of the majors’, classes, and the instructors are different, with the exception of the 2010-2011 academic year where the same instructor taught sections 2 and 3 (majors’ section.) The other sections enroll primarily sophomore non-majors while the majors’ section (section 3) enrolls the Chemistry and Biochemistry First Year majors along with some sophomore non-majors. One could argue, however, that while the students enrolled in section 3 are more invested in the course as majors, they are also not yet acclimated to college life as are the sophomores. Sophomores enrolled in these courses are further along in their math courses and are just

as invested in these courses as most are in the pre-health professional track and seek higher grades. Therefore, while one cannot directly correlate the ACS standardized test data between the three course sections because of the difference in student enrollment, the different instructors, and even the different times in which the course is offered for each section, the fact that the scores are increased significantly does tend to point to the beneficial nature of this teaching strategy.

The purpose of this research project was to determine if incorporating the blended semi-self paced method to the majors general chemistry course at Spelman College was beneficial to the improvement of student knowledge retention, using the past four academic years as the platform of the research. The data collected, shows that the blended method and the gated test system are effective in student knowledge retention and concept mastery. This current academic year has shown that some adjustments may need to be made to continue to show increase in the gated test and the ACS scores within the blended course itself. The instructor has continually modified these courses to incorporate more student-centered activities and to place more responsibility for learning on the students. More work is also being done to determine the preparedness of First Year students coming into the college. Pre-assessment tests are now being administered at the beginning of the first term to determine math preparedness and to assess prior chemistry conceptual knowledge. Preliminary data shows that there is little difference between majors and non-majors in terms of conceptual chemistry knowledge coming into the course. Math preparedness tends to be more of an indicator of success in these courses. Finally, students who have progressed through the majors' sequence are now being followed as they progress through the curriculum. The majority of these students stay together as a cohort when they enroll in the first term Organic Chemistry course. They are given a pre-assessment test in that course that has several questions from the ACS standardized final exam used the previous semester. Analysis of this data will show how students retain knowledge over time. In addition, individual responses to final exam test questions are being analyzed to identify those concepts with which students still have difficulty. This information will be used to revise LOL-IPOPs and/or POGIL worksheets that are associated with specific student learning outcomes in order to better instruct students in those areas.

Like many new conceptual implementations, LOL-IPOPs and POGIL worksheets all could be revised to further improve upon student knowledge retention and concept mastery. In that same sense, LOL-IPOPs and POGIL worksheets have proven to be beneficial to students over the past four academic years. As explained in the methodology section, LOLs are online lectures and IPOPs are puzzle and problem solving activities that correspond to the LOLs. Together they help students with concepts that they may be struggling with. Several students have stated that they rely on LOLs and IPOPs to prepare for class. POGIL worksheets are facilitated in the class room. Students get in groups and work on different conceptual questions and ask the teacher for assistance as needed. Students' working together in a group setting is an example of peer to peer interaction. The idea of peer to peer interaction is to provide students with another way of learning. This idea of peer to peer interaction is a part of the public schools system of teaching techniques. There are nine teaching techniques and peer to peer interaction is number six. All students learn differently and using the type of adaptive learning, give students several different and innovative ways to excel in learning. Blended learning allows students to learn independently, while still receiving teacher assistance to further grasp concepts.

6. Literature Cited

1. Garrison, D.R., H. Kanuka (2004) "Blended learning: Uncovering its transformative potential in higher education," *Internet and Higher Education* **7**, 95-105.
2. Rhode, Jason F. (2009) "Interaction Equivalency in Self-Paced [Online Learning](#) Environments: An Exploration of Learner Preferences. 10.1
3. Green, B. (1971) "Physics Teaching by the Keller Plan at MIT," *American Journal of Physics* **39**, 764-774.
4. Farrell, John J., Richard S. Moog, and James N. Spencer. (1999) "A Guided-Inquiry General Chemistry Course." *Journal of Chemical Education* **76**, p. 570-574.
5. Rogerson, Brian J. (2003) "Effectiveness of a Daily Class Progress Assessment Technique in Introductory Chemistry." *Journal of Chemical Education* **80**, 160-164.