IN-TIME INTERVENTIONS: AN ATTEMPT TO IMPROVE STUDENT PERFORMANCE IN LARGE LECTURE GENERAL CHEMISTRY COURSES

by

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(Under the Direction of Dr. Charles H. Atwood Ph.D.)

ABSTRACT

It has become common knowledge in the chemical education community that large lecture courses result in difficult learning environments for students. Despite this large lecture courses are cost effective and logistically practical for large universities. Students who enroll in large lecture format general chemistry courses are receiving grades of D, F, or W at an alarming rate. Students state that their poor performance is directly related to the depersonalized feel of the large lecture approach. The goal of this research project is to minimize the depersonalized feel of large lecture general chemistry courses, while increasing the academic performance of the students. Three separate in-time interventions are being used to meet this goal.

The first intervention uses internet based instant messaging (IM-Chem) to allow students to ask questions of a teaching assistant during instructional time. Specifics of the implementation will be discussed. Student interviews indicate that this intervention is personalizing the large lecture setting. An analysis of student performance data indicates that participants are 3.10 % more likely than nonparticipants to obtain a grade of C- or higher in the course.

The second intervention consists of remedial help sessions that target students who are at-risk of poor performance on key chemistry concepts during homework assignments and tests. A rigorous definition of at-risk students will be presented. Additionally, data analysis has shown that students who are invited to and attend help sessions are more likely to be successful on key chemistry concepts when compared to their counterparts who were invited but chose not to attend.

The third intervention consists of a Cognitive Load Theory (CLT) adaptation to our homework system, JExam. The tenants of CLT are presented followed by the different CLT adaptations used in computerized homework systems. A preliminary analysis of the CLT static fading adaptation being implemented in JExam will be presented. The data suggest that the probability of students correctly answering difficult chemistry questions increases by an average of 12.76 %.

Finally, an Item Response Theory based study to evaluate the effect on student performance of all the lecture innovations over the past five academic years is presented.

INDEX WORDS: Chemical Education, Instant Messaging, Remedial Help Sessions, At-Risk Students, Cognitive Load Theory, Item Response Theory

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DEDICATION

I would like to dedicate this work to all those people who have inspired me to chase my dreams, especially my wife Jesse and my parents Dana and Judy. Without each of you none of this would have ever been possible.

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Chapter 1: Introduction

General Chemistry at the University of Georgia

General chemistry at the University of Georgia (UGA) is offered as a two-semester sequence. Each student registers for one lecture section and one lab section per semester. There are no recitation sections associated with the course. Lecture sections meet for a total of 150 minutes per week in a 360-seat lecture hall. The average enrollment in the fall semester course, general chemistry I, is 1,550 students (310 students per section). These students are enrolled in one of five sections, which are taught by a total of four different instructors. The average enrollment in the spring semester course, general chemistry II, is 1,000 students (250 students per section). These students are enrolled in one of four sections, which are taught by three different instructors. Students' grades in each course are determined by a combination of ten electronic homework assignments, three eighty-minute electronic exams, and one paper and pencil American Chemical Society (ACS) national exam. All of the electronic homework assignments and tests are administered using our electronic homework and testing system, JExam. Students can complete homework assignments using their laptops or personal computers from any location. Students must complete all electronic exams at a scheduled time in our Chemistry Learning Center. All exams are proctored by teaching assistants (TAs).

The Problem

During the past ten years between ten to fifteen percent of UGA general chemistry students have received grades of D, F, or W. Though this is a tremendous improvement from the thirty percent of students who received D, F, or W grades in the early 1990s, it remains a focus of the department and university. The following research is aimed at lowering the frequency of D, F, and W grades in general chemistry even further. The research implements three interventions in an attempt to increase student performance.

The Three Interventions

The first intervention, IM-Chem, utilizes internet based instant messaging (IM) in an attempt to personalize the large lecture setting. A tremendous amount of research exists about the problems associated with the large lecture setting [1-5]. Students report that the depersonalized nature of the large lecture courses is one of the major reasons they perform poorly [1-5]. Enhancing communication between the students and course instructor has been shown to have a positive impact on student performance [1, 2, 6, 7]. Allowing students to ask questions via IM during large lecture courses is one means of enhancing communication between the students and course instructor. This intervention allowed students who chose to participate the opportunity for a more personalized experience within the confines of a large lecture general chemistry course. Details about the implementation and success of IM-Chem at UGA can be found in chapter 2.

The second intervention, in-time remedial help sessions, seeks to improve the performance of students who are at-risk of performing poorly on key chemistry concepts. Item Response Theory (IRT) analysis and instructor interviews have identified eleven topics that are critical to the success of students in general chemistry at UGA [8]. A mechanism for identifying at-risk students was developed and tested. Since previous research indicated students who received additional instruction performed better on subsequent exams, at-risk students were invited to attend help sessions, which were modeled after supplemental instruction (SI) sessions [5, 9-11]. Each help session targeted one of the eleven key topics. The help sessions utilized cooperative learning based activities to remediate student content knowledge about a key topic prior to the next exam. Topic specific study strategies were also discussed. Additional information about the definition of at-risk students, the implementation of the remedial help sessions, and the success of the sessions can be found in chapter 3.

The third intervention, implementing Cognitive Load Theory (CLT) based homework questions, was aimed at improving the performance of all general chemistry students. All general chemistry students experienced this intervention because homework assignments are a portion of their course grade. Human cognitive architecture consists of a limited working memory and unlimited long-term memory [12-16]. In order for learning to occur, the load exerted by the knowledge to be acquired must be less than the available working memory [15]. CLT aims to minimize knowledge load while promoting knowledge retention or learning [12-16]. Eight electronic homework questions, four from general chemistry I and II respectively, were converted to CLT based questions in our JExam system. Students were then asked similar questions on subsequent exams. The IRT difficulty of the exam questions with and without the CLT based homework questions was evaluated. A decrease in the IRT difficulty of the questions indicates an increase in student knowledge retention with respect to the particular topic being tested. A more detailed explanation of CLT, the question conversion process, and the success of the intervention can be found in chapter 4.

Chapter 5 presents a longitudinal study, fall 2006 through spring 2011, of general chemistry student performance. The study utilizes the average IRT student ability from each year to evaluate the learning gains of students as a result of numerous interventions [17, 18]. Three of those interventions are discussed in chapters 2 through 4. As of the writing of this document, this is the first known attempt at an IRT based longitudinal study in the chemistry domain. Details about the set-up of the study, the necessary data analysis procedures, and the results are discussed.

Chapter 2: IM-Chem

Introduction

Introductory general chemistry courses are often taught in the large lecture format for economic reasons. Teaching and learning in the large lecture format is difficult. A large body of research exists that documents the depersonalized nature of the large lecture setting as one of the major obstacles to learning [1-5]. Both students and instructors in these courses find it difficult, if not impossible, to establish a rapport. A subset of the students in most large lecture courses find themselves enrolled in a class that is larger than their entire high school. These students often find interactions with their peers and instructors difficult in such a setting. Students frequently find asking questions and participating in class discussion in the large lecture setting intimidating [1, 2]. Additionally, students in introductory courses often possess a low intrinsic motivation to succeed because they do not see the connection between the introductory course and their chosen field of study [4]. Combining these factors produces a difficult teaching and learning environment.

Student performance is further negatively impacted by the perceived passive nature of lecture instruction [2, 4]. Students who choose to be passive fail to develop the critical thinking skills necessary to succeed in upper-level coursework and research [4, 5]. Instructors have implemented various forms of enhanced communication in an effort to personalize the large lecture setting while creating a more active learning environment geared toward improving student performance. Dougherty has shown that implementing electronic mail accounts, as a means of dialogue, in large lecture chemistry courses has a positive impact on the number of students receiving a grade of C or higher in the course [6, 7]. Holme has successfully reduced the intimidation of individual question answer scenarios, and personalized the large lecture setting, by utilizing Socratic dialogue with instantaneous small groups [2]. Harwood all but removed the intimidation of the large lecture setting by implementing anonymous "one-minute papers" as a means of summarizing course content and asking questions [1]. One drawback to this method is that students do not receive feedback regarding their questions until the following class period, which has the potential to hinder learning. Enhanced communication using computer-mediated technologies is one way to provide more immediate feedback to students.

Instant messaging (IM) is a means of logging onto a computer network and synchronously communicating with other users [19, 20]. IM began as a text-based platform that has expanded in recent years to include file sharing, audio and video. The real-time communication features of IM make it an ideal way to ask questions and receive immediate feedback. IM accounts also have the potential to be anonymous or semi-anonymous to other users, which reduces the intimidation felt by individuals asking and answering questions. Research has shown that IM also reduces the formality of learning while increasing the sense of community within a course [20]. Based on these characteristics, and provided student interest in utilizing technology in an educational setting exists, IM may be an improved form of enhanced communication for the large lecture setting.

IM has been widely adopted for social and commercial use, but academia has remained reluctant to implement the technology [21]. A 2006 survey of 781 students revealed that 96 % had used IM at some point in the last year. 74 % of IM users reported using IM on a daily basis [21]. Most students began using IM as a means to socialize with family and friends [21]. Over time students began to explore other uses of IM, and 89 % of student users indicate they have used IM for educational purposes [21]. Common educational uses include discussing school tasks, as well as gathering and discussing course related materials [21]. Some academic institutions have begun utilizing IM to improve the language skills of foreign language students through communication with native speakers, while other institutions encourage the use of IM to contact reference librarians for research assistance [21]. A large majority, 86 %, of students surveyed indicate they support wider use of IM in educational settings [21]. The student support of IM stems from their comfort with technology, and their desire to partake in the active learning environment that technology creates [20]. Additionally, students feel more comfortable using technology because of the increased anonymity it provides, particularly when asking questions [22].

It has been suggested that IM might be ideal for the large lecture setting for numerous reasons. Students can engage in discussions that clarify their understanding of course material without interrupting the flow of the lecture [23]. These discussions put students in control of their own learning, which creates an active learning environment in an otherwise passive setting [19, 21]. IM also minimizes the noise and other distractions that would be present if such discussions occurred verbally between hundreds of students [23].

In an effort to personalize the large lecture setting, and improve student performance by creating a more active learning environment, IM was implemented in the large lecture general chemistry program at the University of Georgia. The details of the IM-Chem implementation and its outcomes are presented below.

IM-Chem Implementation

Twenty-six handheld IM devices were purchased for use in introductory general chemistry courses. The IM devices were purchased to limit off-topic multitasking opportunities that are available on personal computers/laptops (i.e. checking email, accessing Facebook®, and/or participating in IM conversations with friends), which have been shown to have a negative impact on student performance [23, 24]. The devices came preloaded with software compatible with the MSN instant messenger and a wireless network adaptor. Each device was assigned an MSN username and password, which was maintained throughout its use. IM devices were made available for interested students to pick-up prior to lecture. Any remaining devices were randomly distributed throughout the 360-seat lecture hall as lecture began. One IM device was available for every fourteen students. Students were encouraged to discreetly acquire and utilize the devices as needed.

During each lecture period students could use the IM devices to question a teaching assistant (TA) located in the lecture hall. Each question began with the student's university username. All conversations were saved for later analysis. If several students asked similar questions, the TA notified the instructor who provided clarification on the topic to the entire class. Questions were answered in the order the TA received them. Student use of the IM devices was voluntary. No additional course credit was offered. Students were also encouraged to ask questions verbally during lecture.

IM-Chem was implemented in one section of general chemistry in fall 2008 and two sections of general chemistry in spring 2009, fall 2009, and spring 2010. All of the fall sections were general chemistry I courses. Spring sections were general chemistry II courses. The same instructor taught all of the sections. All sections completed ten graded homework assignments, three exams, and one American Chemical Society (ACS) final exam. Table 1.1 summarizes the student participation in IM-Chem during each term.

Table 2.1: Student participation in IM-Chem broken down by term and section.

Term/ Section	Enrollment	# of IM-Chem Participants	# of IM-Chem Questions
Fall 2008 / #1	357	67	165
Spring 2009 / #1	363	56	110
Spring 2009 / #2	341	55	106
Fall 2009 / #1	348	78	200
Fall 2009 / #2	351	87	230
Spring 2010 / #1	354	36	75
Spring 2010 / #2	355	43	86
Totals	2469	422	972

Student questions were classified into two categories, content and procedural. Content questions related to course material, while procedural questions related to the day-to-day operations of the course. Of the 972 questions asked, 860 (88.5%) were content oriented and 112 (11.5%) were procedural. A few examples of content and procedural questions are shown below.

Sample Content Questions

1. "When you are doing problems with the unit factor method, is the number of significant figures based just on the original number or on the numbers you multiply by as well?"
2. "What is the difference between a formula unit and a molecule?"
3. "Why are electrolytes important for your body?"
4. "In symmetrical compounds are the electrons in bonds and lone pairs equally shared?"
5. "How do you find the number of electrons in an ion? I know the number of protons stay the same, and you get the number of neutrons using subtraction."

Sample Procedural Questions

1. "I was looking on WebCT, and it looks like my clicker never got registered. What should I do?"
2. "Where is the chemistry learning center?"
3. "Why did I get an email saying I am having trouble with limiting reactions on my homework and I should attend a help session when I got 100 on the homework?"

4. “What do you think would be the best way to study for the final?”
5. “Will chapter 13 be on the upcoming test?

Results and Discussion

Course grades were used to determine the impact IM-Chem had on student performance. Of the 422 IM-Chem participants, 331 (78.4%) achieved a grade of C- or higher versus 1542 (75.3%) of the 2047 non-participants (2469 students – 422 participants). Based on this comparison, IM-Chem participants were 3.10% more likely to achieve a grade of C- or higher. The mean course grade, on a 4.0-scale, for participants was 2.43 ± 1.31 versus 2.29 ± 1.32 for non-participants. A one-tailed t-test confirmed that participants had a significantly higher mean course grade, at the 95% confidence interval, when compared to non-participants ($t = 2.048$, $p = 0.020$). Separating students by course and reevaluating the difference in mean course grades between participants and non-participants indicated that IM-Chem had a greater impact on the student performance of general chemistry I students. In general chemistry 1 participants ($n = 232$, mean gpa = 2.42) outperformed non-participants ($n = 824$, mean gpa = 2.19) at the 95% confidence interval ($t = 2.230$, $p = 0.001$). There is no significant difference between participants ($n = 190$, mean gpa = 2.45) and non-participants ($n = 1223$, mean gpa = 2.36) in general chemistry II at the 95% confidence interval ($t = 0.980$, $p = 0.164$). Dougherty reports similar gains in student performance when enhanced communication in the form of electronic mail accounts were implemented in large lecture general chemistry courses [6, 7].

Based on the data collected, it is difficult to attribute the gains in student performance solely to participation in IM-Chem. However, participation in IM-Chem requires critical and active evaluation of lecture material in the effort to clarify one's understanding through a question-answer format. There exists little debate about the fact that active learners outperform their passive counterparts during course assessments. It seems reasonable to surmise that the performance gains exhibited by IM-Chem participants are due in large part to the active learning nature of the activity.

A closer examination of Table 1 reveals that general chemistry I students utilize IM-Chem with a greater frequency compared to general chemistry II students. The decrease in number of questions in general chemistry II courses is one of the reasons that there is not a significant difference in student performance among general chemistry II participants and non-participants. It should be noted that though there was a decrease in IM-Chem participation throughout the two-course sequence, there was a perceived increase in the number of verbal questions during the same period of time. No formal data was collected with regards to this trend, but Harwood observed a similar trend when anonymous "one minute papers" were implemented [1]. Additionally, regardless of the course, when difficult topics, such as Lewis acid base theory were presented, the number of IM-Chem and verbal questions increased sharply. Harwood also reported a similar trend [1].

At the conclusion of each term volunteers were recruited to share their thoughts and opinions about IM-Chem. Thirty-one students participated in audio-recorded interviews. Each interview was transcribed for analysis. Each interview consisted of a standard set of questions. Additional questions were added after each term to investigate emerging trends. Questions utilized in the interviews were as follows.

Student Interview Questions Fall 2008-Spring 2009

1. Why did you choose to ask questions using the instant message devices?
2. Would you have asked the same questions verbally in lecture that you asked using instant messaging? Why or why not? How would you get your question answered?
3. Did you feel the answers to the questions you asked were adequate? Why or why not?
4. What advantages and disadvantages do you see to the instant message service?
5. Do you feel the number of instant messaging devices was adequate, and if not what is an adequate number?
6. Did you feel that the instant messaging service was a distraction in class?
7. Should the instant messaging program continue to be offered in general chemistry courses? Why or why not?

Student Interview Questions Fall 2009-Spring 2010

1. Why did you choose to ask questions using the instant message devices?
2. Would you have asked the same questions verbally in lecture that you asked using instant messaging? Why or why not? How would you get your question answered?
3. Did you feel the answers to the questions you asked were adequate? Why or why not?
4. What advantages and disadvantages do you see to the instant message service?
5. Do you feel the program gives the large lecture class a more personalized feel?

6. Do you feel the number of instant messaging devices was adequate, and if not what is an adequate number?
7. Do you feel that you can obtain a device when you need one, either by picking a device up at the beginning of class, or asking a neighbor to pass you one during class?
8. Did you feel that the instant messaging service was a distraction, in any way, during class?
9. Should the instant messaging program be continued/expanded in general chemistry and/or other courses? Why or why not?

When the students were asked how they would get their questions answered if IM-Chem was not available, 16 (51.6%) said they would not ask their question, 8 (25.8%) said they might find another way to ask their question outside of class, if they could remember the question long enough, and 7 (22.6%) said they would ask their question in class verbally. This data, and the interview quotes below about why students utilize IM-Chem as well as the advantages and disadvantages of IM-Chem, suggest that students utilized IM-Chem because they are too shy and/or intimidated to ask questions in front of a large group of their peers.

> “I guess one advantage is you don’t have to talk in front of 300 people, because that is intimidating. Another advantage it allows for more detailed answers. A disadvantage would be, well I can’t really think of one, but typing could be distraction but not really a big deal.

> “I think it is a good way, like if some people are shy and want to get their question answered. Or if people think their question only applies to them it is a good way. I think a disadvantage is there are not enough devices.”

"I guess first of all intimidation and I can get the answers right away using the Zipit. Also the questions I have don't always pertain to exactly what we are discussing in class at the moment."

IM-Chem provides these students with a semi-anonymous way to ask their questions in the large lecture setting. Harwood observed similar results with the "one minute paper" [1].

After reviewing interview transcripts at the conclusion of the spring 2009 term, it was determined that students were hinting at IM-Chem personalizing the large lecture setting. The 15 students interviewed in the fall 2009 and spring 2010 terms were asked directly about this topic, and 14 (93.3%) responded that they felt IM-Chem did personalize the large lecture setting compared to 1 (6.7%) who said it did not. The majority of students who indicated IM-Chem personalized the lecture stated that the personal connection was the result of immediate feedback tailored to their specific question that IM-Chem provided. The interview quotes shown below illustrate this point.

"It does personalize the large lecture because sometimes you just need that one-on-one explanation. You can also understand something through a continuous dialogue when needed, which is hard in a large lecture class."

"Yeah it personalizes the class because you are directly asking your question, and receiving a direct answer to your question."

"Yeah it definitely personalizes the large lecture. You don't have to ask a question in front of 300 people. You can ask your question and get a personal answer."

Webster provides an excellent explanation of the importance of timely and thoughtful feedback in the large lecture setting [5]. It is interesting to note that the student who stated that IM-Chem did not personalize the lecture was of the opinion that personalizing college classes of any kind was up to the student. This student felt that students had to possess the initiative to form a connection with the instructor on his or her own time.

Conclusions

Implementation of IM-Chem in large lecture general chemistry courses has had a positive impact on student performance. IM-Chem participants had a mean course grade that was 0.14 GPA units higher than non-participants. Gains in student performance are attributed to the active learning environment that IM-Chem participants experienced. Additionally, an overwhelming majority of participants stated that IM-Chem personalized the large lecture setting by providing them with an unintimidating way to ask questions and individualized answers to those questions. IM appears to be an excellent form of enhanced communication for large lecture settings.

Chapter 3: In-time Remedial Help Sessions: An Attempt to Improve the Academic Performance of At-risk General Chemistry Students

Introduction

In recent years there has been growing concern over the number of D, F, and W grades in general chemistry courses. In an effort to reverse this trend, researchers have worked to identify the characteristics of students who are at-risk of receiving a grade of D, F, or W. At-risk students have then been exposed to various forms of additional instruction in an effort to improve their academic performance. The following study seeks to produce a more rigorous content specific definition of at-risk students, and provide those students with immediate “in-time” remediation in an effort to improve their academic performance.

Background Information

Typically first generation college students, minorities, and student athletes are categorized as students at-risk of performing poorly in college courses [9]. The common variable among all of these groups is their first generation status. These individuals have no one, parents, guardians, or friends, to turn to for college success advice. Each one of these students must figure out how to succeed in college on their own. Significant percentages of these students eventually leave college entirely. This study seeks to establish a more rigorous chemistry content specific definition of at-risk students. Once these at-risk students are identified, additional instruction can be aimed to remediate their content knowledge, which in turn will offer them a better chance of succeeding in the course. This success will hopefully translate from one course to the next, and eventually lead to college graduation.

One highly effective additional instruction model is supplemental instruction (SI) [5, 9-11]. SI offers students additional voluntary time-on-task activities outside of normal class meeting times. SI is usually offered in conjunction with large enrollment courses. The primary goal of SI is to foster conceptual understanding [10, 11]. SI sessions usually focus on both course content and study-skills [10, 11]. The number of SI sessions per week, the length of the sessions, and the structure of the sessions vary greatly. An SI director usually coordinates all of the SI leaders and sessions associated with a given course [10, 11]. SI sessions are led by SI leaders, teaching assistants (TA's) or upper-level undergraduate students, who have successfully completed the course [10, 11]. Many SI sessions center around informal discussions based on student questions. Research has shown that students perform better as a result of and prefer more structured SI sessions [11].

This study modeled a more structured version of SI. All of the sessions in this study were led by the same course TA. The sessions also took advantage of the many benefits of cooperative learning. Cooperative learning is defined as any activity where peers collaborate to gain knowledge. The benefits of cooperative learning can be separated into four major categories [9]. First, students are forced to take responsibility for their own learning in an active manner [9]. Second, students typically attain higher-order thinking skills [9]. Third, students typically display higher retention rates [9]. Finally, students generally have a more positive attitude towards the subject matter [9]. Many articles regarding the successful implementation of cooperative learning in the chemistry classroom exist in the literature including those by Cooper [25] and Towns [26]. Many examples of the impact cooperative learning has had on student performance can also be found in the chemical education literature [6, 7, 27-35]. Summaries of this information, as well as additional information, can be found in several literature reviews conducted on the subject [36, 37]. To maximize potential learning gains supported by the cooperative learning literature, all of the help sessions in this study contain cooperative learning based course content activities.

Help Session Specifics

Item response theory (IRT) analysis of all exams administered to general chemistry students at the University of Georgia (UGA) between fall 2001 and spring 2009 along with interviews of general chemistry instructors generated a list of the eleven topics key to student success in the two semester general chemistry sequence. Details about the IRT analysis that yielded a substantial portion of this list are discussed by Schurmeier et. al. [8]. Table 3.1 presents the eleven key topics. Topics one through six are covered in first semester general chemistry at UGA. Topics seven through eleven are covered in second semester general chemistry at UGA.

Table 3.1: The eleven topics key to the success of general chemistry students at the University of Georgia.

Topic #	Topic
1	Molecular representation of physical and chemical changes
2	Complex unit conversions
3	Limiting and excess reagent calculations
4	Interpreting quantum numbers
5	Ionic vs. covalent compounds, concentrated vs. dilute solutions, weak vs. strong vs. non-electrolytes
6	Bond polarity, molecular shape, and molecular polarity
7	Lewis acids and bases
8	Intramolecular vs. intermolecular forces
9	Freezing point depression
10	Thermodynamic moles of reaction
11	Equilibrium and percent ionization

Since UGA general chemistry courses do not have associated recitation sections, a separate help session was designed for each topic in an attempt to improve the academic performance of students identified as at-risk of poor performance on that topic on a subsequent test. Help sessions were offered to students who were identified as at-risk in the 2009-2010 and 2010-2011 academic years.

Students were identified as at-risk of poor performance on a particular topic if they incorrectly answered all of the homework questions related to that topic. This definition was developed after a detailed analysis revealed a correlation between incorrect homework question responses and subsequent test question responses. Students in the 2008-2009 academic year received standard instruction with regards to the eleven key topics. Table 3.2 summarizes the correlation between 2008-2009 students that missed all homework questions related to a key and their subsequent performance on test questions related to that topic.

Table 3.2: 2008-2009 student performance on homework and test questions related to the eleven key chemistry topics at UGA.

Topic	# of Students that Missed All Relevant Homework Questions	# of Students that also Missed 50% of Relevant Test Questions	%
1	428	86	20.09
2	176	136	77.27
3	904	437	48.34
4	280	142	50.71
5	1142	1079	94.48
6	880	321	36.48
7	293	104	35.49
8	409	316	77.26
9	567	314	55.38
10	493	234	47.46
Total	**5572**	**3169**	**56.87**

There were 5,572 occurrences of students missing all of the homework questions related to a particular topic. In 3,169 of those 5,572 occurrences, or 56.87% of the time, students also missed at least half the questions about that topic on a subsequent test. Therefore, students who miss all of the homework questions related to a particular topic were labeled as at-risk of poor performance on that topic on a subsequent exam.

All homework assignments were completed using UGA's electronic homework and testing system, JExam. Immediately following the completion of a homework assignment that contained questions related to one of the eleven key topics, JExam generated a list of students who missed all of the relevant questions. All of the identified students were invited via email to attend a help session focused on that topic. Help sessions were held on the two days following the invitation, which insured the help sessions occurred before the students were tested on the key topic. This "in-time" approach was chosen so an immediate impact on student performance could occur. It was hoped that if students saw an immediate impact on their performance, they would modify future study habits. Student attendance at help sessions was voluntary. Each help session was held in the early evening, because courses contained no mandatory recitation sections, and lasted a total of 75 minutes. During each session one study skills activity and one cooperative learning based course content activity focused on the key topic targeted at that session.

The following lesson plans detail the exact activities undertaken at each session. Note that some help sessions have two lesson plans because the content of the lesson was modified between the 2009-2010 and 2010-2011 academic years.

Help Session 1: Molecular Representations of Physical and Chemical Changes

Study Skills Activity: A review of the chemistry tutoring services available to students at UGA was presented. Services highlighted included the Chemistry Learning Center and Milledge Hall Learning Center

Course Content Activity: Working in groups of three to four, students were asked to represent the following physical and chemical changes on the atomic/molecular scale. Each group was asked to come to an agreement on the appropriate representation. Groups then presented their representations, and a class wide discussion resulted in one chemically correct representation. Each representation was then classified as a physical or chemical change.

Problem 1: Draw a molecular representation of a container that is holding ten molecules of liquid water. Draw a second representation that shows the same container after all the liquid water has boiled. Is this a physical or a chemical change? How would you know?

Problem 2: Create a molecular representation of the following: one atom of copper, Cu, reacts with two molecules of silver nitrate, $AgNO_3$, to produce two atoms of silver, Ag, and one molecule of copper(II) nitrate, $Cu(NO_3)_2$. Be sure to make each different type of atom a different colored sphere. Is this a physical or a chemical change? How would you know?

Problem 3: Create a representation of one container that holds ten atoms of solid iron, and a second container that holds ten molecules of chlorine gas. Create a molecular representation of what happens if containers one and two are mixed in such way to produce a physical change. Create a molecular representation of what happens if a chemical change results in the formation of $FeCl_2$ when containers one and two are mixed.

Problem 4: Draw a molecular representation of each of the following physical/chemical processes: freezing and combustion. Use three molecules of methane, CH_4, in your representations.

Help Session 2: Dimensional Analysis and Unit Conversions (2009-2010)

Study Skills Activity: A PowerPoint presentation on student responsibility and academic success was presented. The presentation was followed by a brief discussion of student and instructor responsibilities in the collegiate classroom.

*Course Content Activity***:** Students were presented with blank note cards, and asked to place the unit conversions shown below on each card.

1m/1000mm	100cm/1m	1in./2.54cm
1ft/12in	1mi./5280ft	60s/1min
60min/1hr	12in./1ft	2.54cm/1in
4quarts/1gal	1000mL/1L	$1cm^3$/1mL
mm	ft	m/s
cm^3	gal	mi/hr
ft^2	cm^2	1cm

Then the students were presented, via PowerPoint, with the three problems shown below. Problems were presented one at a time. The students, working in groups of three to four, were asked to first arrange the note cards in such a way that the appropriate solution to the problem could be obtained. All members of the group had to agree on the order. Once the majority of groups had agreed upon an order for the cards, the correct sequence of unit conversions was revealed and discussed. The students, in their groups, were then asked to calculate a numeric solution to the problem, which must include the proper units.

Problem 1: You have a rope that is 112.0 mm long. How long is the rope in feet?

Problem 2: You are driving down Interstate 85, where the speed limit is 65.0 mi./hr., at a speed of 38.0 m/s. You pass a cop, who is clocking traffic on the side of the road, should you be worried about getting a speeding ticket?

Problem 3: You own a rectangular pool that is 25.0 ft by 30.0 ft and contains 3.00×10^4 gallons of water. How many centimeters deep is the water in your pool?

Help Session 2: Dimensional Analysis and Unit Conversions (2010-2011)

Study Skills Activity: A PowerPoint presentation on student responsibility and academic success was presented. The presentation was followed by a brief discussion of student and instructor responsibilities in the collegiate classroom.

Course Content Activity: The students were presented, via PowerPoint, with the four problems shown below. Problems were presented one at a time. The students, working in groups of three to four, were asked to identify the goal of each problem with its proper units. Students were then asked to generate a step-by-step plan to solve the problem. All members of the group had to agree on the plan before the facilitator approved it. Once the plan was approved each group had to come up with a numeric solution for the problem. Each group displayed their work and final answer on the chalkboard for class analysis and discussion.

Problem 1: You have a rope that is 112.0 mm long. How long is the rope in feet?

Goal: Length of rope in feet

Plan:

1. Convert mm to m
2. Convert m to cm
3. Convert cm to in.
4. Convert in. to ft.

Problem 2: You are driving down Interstate 85, where the speed limit is 65.0 mi./hr., at a speed of 38.0 m/s. You pass a cop, who is clocking traffic on the side of the road, should you be worried about getting a speeding ticket?

Goal: Speed in mi./hr.

Plan:

1. Convert m to cm
2. Convert cm to in.
3. Convert in. to ft.
4. Convert ft. to mi.
5. Convert s. to min.
6. Convert min. to hr.

Problem 3: You own a rectangular pool that is 25.0 ft by 30.0 ft and contains 3.00×10^4 gallons of water. What is the height of the water in centimeters? If a person is 5.30 ft tall and they are standing in the pool, will any portion of their head be above water?

Goal: The height of the water in centimeters and feet

Plan:

1. Calculate area in ft^2
2. Convert ft^2 to cm^2
3. Convert gal. to cm^3
4. Calculate height of water in cm
5. Convert cm to ft.

Problem 4: Lead has a density of 11.3 g/cm^3. If you have a cube of lead that has a mass of 10.5 cg what is the area of one face of that cube in cm^2?

Goal: Find area of one face of the cube in cm^2.

Plan:

1. Convert cg to g
2. Calculate volume of lead cube in cm^3
3. Calculate length one edge of lead cube in cm
4. Calculate area of one face of lead cube in cm^2

Help Session 3: Limiting and Excess Reactant Calculations

Study Skills Activity: Make a problem-solving plan based on the mole bridge diagram. The diagram was developed through group discussion and sketched on the board.

Course Content Activity: Students worked in groups of three to four to generate a problem-solving plan and solve the limiting and excess reactant problems below. Students also learned how to correctly identify a limiting reactant problem.

Problem 1: What masses of H_2O and CO_2 are produced when 16.0 g of CH_4 reacts with 48.0 g of O_2? How much CH_4 and O_2 will remain after the reaction is complete?

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

Problem 2: What are the maximum masses of $Ni(OH)_2$ and NaCl that can be produced when 25.9 g of $NiCl_2$ reacts with 10.0 g of NaOH? How much $NiCl_2$ and NaOH with remain after the reaction is complete?

$$NiCl_2 + NaOH \rightarrow Ni(OH)_2 + NaCl$$

Problem 3: If 5.00 mL of 0.558 *M* HNO_3 solution reacts with 45.55 mL of 0.0515 *M* $Ba(OH)_2$, how many grams of $Ba(NO_3)_2$ and H_2O are produced? What volume of HNO_3 and $Ba(OH)_2$ remain?

$$HNO_3 + Ba(OH)_2 \rightarrow Ba(NO_3)_2 + H_2O$$

Help Session 4: Interpreting Quantum Numbers

Study Skills Activity: The city of "Periodic Table" analogy for quantum numbers and electrons was presented. The analogy includes seven streets equivalent to n, four neighborhoods equivalent to *l*, house number equivalent to m_l, and upstairs or downstairs resident equivalent to m_s. The elements next to each other on the periodic table do not share a house.

Course Content Activity: The content portion of the session began with a brief lecture that defines and gives a simple interpretation of each quantum number.

Activity 1: Students were shown how to complete table 3.3, all possible quantum number values for n=1 and n=2 energy levels. Additionally, students were shown how to determine the total number of electrons in each energy level and subshell. In groups of three to four, students worked to complete a blank table of all possible quantum numbers and the total number of electrons in each energy level and subshell for the n=3 and n=4 energy levels.

Table 3.3: All of the possible quantum number values for the first four energy levels of an atom.

n	ℓ	m_ℓ	m_s	ℓ Max e^-	n Max e^-
1	0 (1s)	0	-1/2, +1/2	2	2
2	0 (2s)	0	-1/2, +1/2	2	8
2	1 (2p)	-1, 0, +1	-1/2, +1/2 For all m_ℓ	6	8
3	0 (3s)	0	-1/2, +1/2	2	18
3	1 (3p)	-1, 0, +1	-1/2, +1/2 For all m_ℓ	6	18
3	2 (3d)	-2, -1, 0, +1, +2	-1/2, +1/2 For all m_ℓ	10	18
4	0 (4s)	0	-1/2, +1/2	2	32
4	1 (4p)	-1, 0, +1	-1/2, +1/2 For all m_ℓ	6	32
4	2 (4d)	-2, -1, 0, +1, +2	-1/2, +1/2 For all m_ℓ	10	32
4	3 (4f)	-3, -2, -1, 0, +1, +2, +3	-1/2, +1/2 For all m_ℓ	14	32

Activity 2: Once the chart was complete, students utilized the chart to help solve the six problems below. Students listed the maximum number of electrons in each case.

1. 8p subshell:
2. n=1:
3. $8d_{x^2y^2}$:
4. n=3, l=2:
5. n=5, l=3, m_l=-1:
6. n=4, l=3, m_l= 4:

Activity 3: Next, students were shown pictures of three different orbitals and asked to present a valid set of quantum numbers for each orbital. Pictures shown were of p, s, and d orbitals.

Activity 4: Using PowerPoint, the layout of s, p, d, and f elements on the periodic table was presented. The city of periodic table analogy was utilized to show how quantum numbers relate the periodic table and electron configurations.

Activity 5: The electron configuration of Al was presented. How to assign quantum numbers to the first few electrons was demonstrated. Students worked in groups of three to four to assign the quantum numbers to the remainder of the electrons in aluminum's configuration.

Help Session 5: Covalent vs. Ionic Compounds, Concentrated vs. Dilute Solutions, and Strong vs. Weak vs. Non-electrolytes

Study Skills Activity: A summary of the following key sets of rules and tables were presented. All of tables and rules can be found in Chemistry, 9th Edition by Whitten et. al. [38]. Students were encouraged to make note cards to assist them in remembering this information.

1. Rules for assigning oxidation numbers-Ch. 5, pg. 192
2. Common strong and weak acids-Ch. 6, pg. 214, tables 6-1 and 6-2
3. Common strong and weak bases-Ch. 6, pg. 216, table 6-3
4. Solubility guidelines-Ch. 6, pg. 217, table 6-4
5. Formulas and names of some common ions-Ch. 6, pg. 222, table 6-6
6. Formulas of –ic acids, Ch. 6, pg. 223, table 6-7

Course Content Activity: A jeopardy game was played, which stressed topics in the following five categories.

1. Strong vs. Weak vs. Non-electrolytes
2. Concentrated vs. Dilute solutions
3. Number of ions formed in solution
4. Solution descriptions using images
5. Ionic vs. covalent compounds

Students played the game in teams of five to six people. Each team attempted every question. The team with the highest score was the winner.

Help Session 6: Bond Polarity, Molecular Shape, and Molecular Polarity

Study Skills Activity: Reviewed strategies related to taking multiple-choice exams.

Course Content Activity: Students worked in groups of three to four to produce the following information about each molecular formula.

1. Lewis dot structure
2. Generic (ABU) formula
3. Electronic geometry
4. Valence bond theory orbital hybridization
5. Molecular geometry
6. Description of each bond's polarity
7. Description of the molecule's polarity

The molecules used for this activity are listed below.

1. SeO_2
2. PH_3
3. XeF_4
4. ICl_3
5. SF_4
6. $CCl_2COC_2CHOHCHNH$

Help Session 7: Lewis Acids and Bases

Study Skills Activity: Reviewed the guidelines for drawing Lewis dot structures outlined below.

- Assume all molecules follow the octet rule
  - Exceptions:
    - Molecules containing B (usually three bonds, 6e-)
    - Molecules containing Be (usually two bonds, 4e-)
    - Molecules that obviously have more than four single bonds to the central atom (example XeF_6)
- Octet rule: Many atoms strive to have eight valence electrons to be stable
  - Exception: H atoms only need two valence electrons to be stable
- Central atom can usually be deduced using common sense but when in doubt there are two guidelines to follow
  - The central atom is the element needing the most electrons to fill its octet.
  - If two atoms need the same number of electrons to fill their octet, the least electronegative of the two elements is the central atom.

Course Content Activity: Students worked in groups of three to four to identify Lewis acids and bases in given chemical reactions. Students first reviewed some vocabulary relevant to Lewis acid base theory. Then students drew Lewis dot structures of all species in each reaction. Next, curved arrows were drawn to represent the flow of electrons. Each group shared their structures with the class. Through group discussions the correct answer to each question was revealed.

Lewis acid base theory:

- Lewis acid base theory looks at the transfer of electrons (e-) as opposed to protons (H+).
- An electrophile is an electron loving species. This species accepts an electron pair in chemical reactions.
    - Electrophiles are acids according to all three acid base theories we have studied.
- A nucleophile is a nucleus loving species. This species donates an electron pair to form a coordinate covalent bond in chemical reactions.
    - Nucleophiles are bases according to all three acid base theories we have studied.
- A Lewis acid is a species that accepts an electron pair. (electrophile)
- A Lewis base is a species that donates an electron pair. (nucleophile)
- A Coordinate covalent bond is a bond in which both shared electrons are from one species.

Reactions to be utilized:

1. $NH_3 + BCl_3 \rightarrow Cl_3B : NH_3$

2. $H_2O + H_2O \rightarrow H_3O^+ + OH^-$

3. $AlCl_3 + Cl^- \rightarrow AlCl_4^-$

4. $SnCl_4 + 2Cl^- \rightarrow SnCl_6^{2-}$

5. $Na^+ + 6H_2O \rightarrow Na(H_2O)_6^+$

6. $H^- + H_2O \rightarrow H_2 + OH^-$

Help Session 8: Intermolecular vs. Intramolecular Forces (2009-2010)

Study Skills Activity: Discussed effective note taking strategies and effective use of lecture notes in test preparation.

1. Students individually made a list of note taking strategies they use in class
2. Students individually made a list describing how they use their notes to prepare for a test
3. A group discussion of student note taking strategies and use of lecture notes for test preparation took place
4. The strategies of parallel note taking and annotation were discussed.

Course Content Activity:

1. The students individually made a list of all the intermolecular and intramolecular forces they can think of.
2. The students individually ranked the strength of the intermolecular and intramolecular forces
3. Students discussed in groups their lists of forces and their corresponding strengths
4. In groups students drew Lewis dot structures of two methane molecules:
    a. Students identified all the intermolecular and intramolecular forces in their diagram.
5. A class list of forces and their corresponding strengths was composed

6. A class discussion of the proper diagram and force labeling for the methane problem occurred.
7. Students, working in groups, were asked to rank the following substances in order of increasing boiling points.
    a. Identify the dominant intermolecular force of each molecule
    b. Strong intermolecular force = high boiling point
    c. Substances used: hydrogen < methane < hydrogen sulfide < water < potassium bromide < lithium chloride < calcium chloride
8. Students, working in groups, were asked to rank the following substances in order of decreasing vapor pressure.
    a. Identify the dominant intermolecular or intramolecular force in each molecule
    b. Strong intermolecular force = high boiling point = lower vapor pressure
    c. Substances used: argon > ethane > hydrogen chloride > methanol > ethanol > diamond
9. Students, working in groups, were given a graph of boiling point vs. molar mass of the hydrogen halides.
    a. Students placed the 4 hydrogen halides at the appropriate point on the graph
    b. Students provided a succinct written scientific explanation of the trend shown on the graph.

Help Session 8: Intermolecular vs. Intramolecular Forces (2010-2011)

Study Skills Activity: Discussed effective note taking strategies and effective use of lecture notes in test preparation.

1. Students individually made a list of note taking strategies they use in class
2. Students individually made a list describing how they use their notes to prepare for a test
3. A group discussion of student note taking strategies and use of lecture notes for test preparation took place
4. The strategies of parallel note taking and annotation were discussed.

Course Content Activity:

1. Students individually made a list of all the intermolecular and intramolecular forces they could think of.
2. Students individually ranked the strength of all their listed forces
3. Students discussed in groups their lists of forces and their corresponding strengths

4. Students, working in groups, were asked to draw the Lewis dot structures and label all of the intramolecular and intermolecular forces in each of the items listed below. Once all groups completed the exercise a class discussion occurred.
   a. Two methane molecules
   b. A diflurомethane molecule and a xenon tetrafluoride molecule
   c. A formula unit of sodium chloride and a water molecule
5. Students, working in groups, were asked to rank the following substances in order of increasing boiling points.
   a. Identify the dominant intermolecular force of each molecule
   b. Strong intermolecular force = high boiling point
   c. Substances used: hydrogen < methane < hydrogen sulfide < water < potassium bromide < lithium chloride < calcium chloride
6. Students, working in groups, were asked to rank the following substances in order of decreasing vapor pressure.
   a. Identify the dominant intermolecular or intramolecular force in each molecule
   b. Strong intermolecular force = high boiling point = lower vapor pressure
   c. Substances used: argon > ethane > hydrogen chloride > methanol > ethanol > diamond

7. Students, working in groups, were given a graph of boiling point vs. molar mass of the hydrogen halides.
    a. Students placed the 4 hydrogen halides at the appropriate point on the graph
    b. Students provided succinct written scientific explanations of the trend shown on the graph.

Help Session 9: Freezing Point Depression

Study Skills Activity: A review of the steps, listed below, involved in converting from one concentration unit to another took place.

1. Assume that you have the amount stated in the denominator of the given concentration.
   a. Molarity: 1 L of solution
   b. Molality: 1 kg of solvent
   c. Mole fraction: 1 mole of solution
   d. Mass percent: 100 g of solution
2. Calculate the grams of solute, grams of solvent, and grams of solution.
   a. Remember mass of solution = mass of solute + mass of solvent
3. Calculate the new concentration unit.
   a. Mole Fraction: X_A = moles A / (moles of A + moles B) = moles A / moles solution
   b. Molarity: M = moles solute / L solution
   c. Molality: m = moles solute / kg solvent
   d. Mass percent: $\%_A$ = (mass A / (mass A + mass B)) x 100% = (mass A / mass solution) x 100%
4. Remember that density is grams of solution / mL of solution

Course Content Activity: Students worked in teams of three to four to attempt solve the following problem.

Useful Equations:

$$\Delta T_f = T_{f(H2O)} - T_{f(substance)}$$

$$\Delta T_f = iK_f m$$

$$K_{f(H2O)} = 1.86\ °C/m$$

$$i = \Delta T_{f\ (observed)}/\Delta T_{f\ (nonelectrolyte)}$$

Available Solutions:

0.150 *m* sucrose ($C_{12}H_{22}O_{11}$) MW = 342.30 g/mol

0.200 *m* NaCl MW = 58.44 g/mol

0.200 *m* $CaCl_2$ MW = 110.98 g/mol

The Problem: After a recent snowstorm Athens-Clarke County and the Georgia Department of Transportation teamed up to find the best solution to treat roads in order to prevent icing at a temperature of -10.49°C (13.11°F). A company was hired to analyze 3 possible solutions (0.150 *m* sucrose, 0.200 *m* NaCl, and 0.200 *m* $CaCl_2$), and after two weeks they had only managed to produce the graph shown below. The organizations turned to the chemistry department at UGA to complete the analysis. Using the given information above, the information in this question, and the graph below, complete the data table and associated questions. Be prepared to defend your answers.

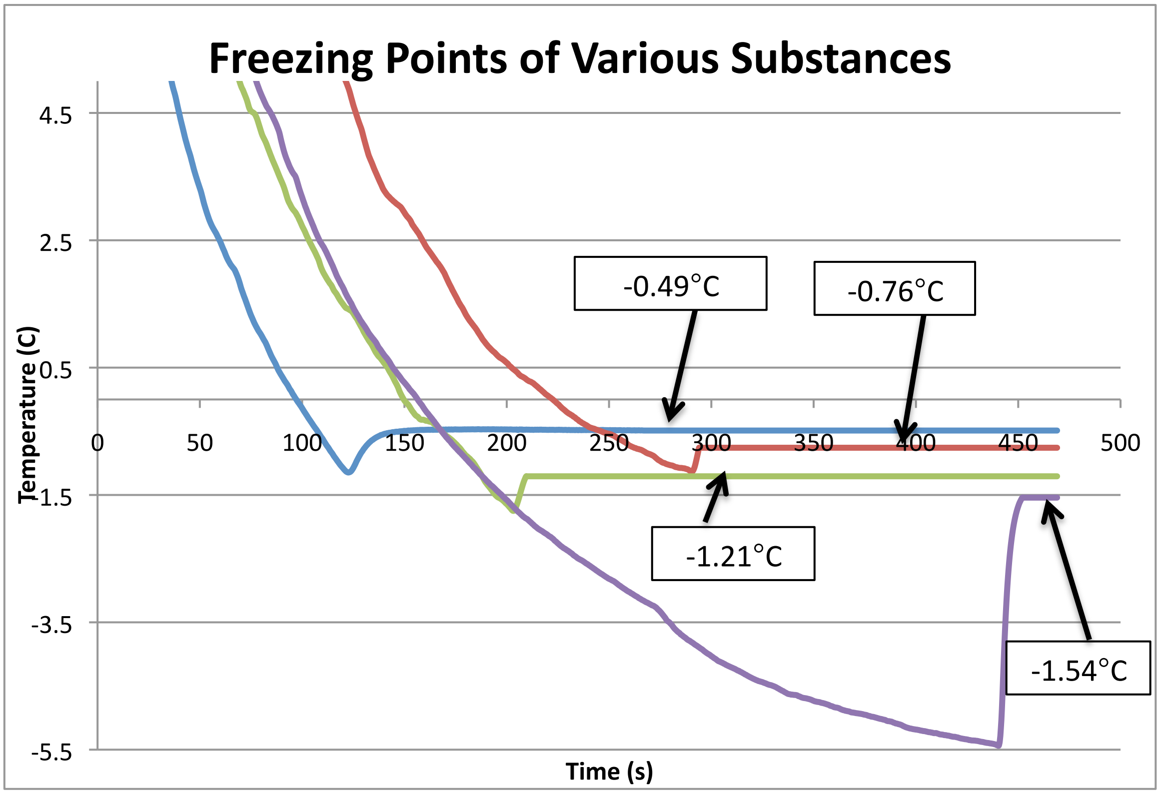


Figure 3.1: Freezing point curves for water and other various aqueous solutions.

Table 3.4: Freezing point depression data for water and other aqueous solutions depicted in figure 3.1.

Line #	T_f (°C)	ΔT_f (°C)	**i**	**Solution**	***m* to reach -10.49°C**	**g of solute/ 1 kg H_2O**
1	-0.49	n/a	n/a	H_2O	n/a	n/a
2	-0.76	0.27	0.97	Sucrose	5.54	1.90×10^3
3	-1.21	0.72	1.94	NaCl	2.77	162
4	-1.54	1.05	2.82	$CaCl_2$	1.91	212

*The student version of this table is blank

Question 1: Which solution would be most effective at preventing freezing on roadways at temperatures below -10.49 °C? Justify your answer with an explanation.

Question 2: If all of the solutes can be purchased at the same price per gram, which solution is most cost effective for Athens-Clarke County and the Georgia Department of Transportation to use? Justify your answer with an explanation.

Question 3: Express 2.77 *m* in units of molarity, mole fraction, and percent by mass. Assume this is a NaCl solution with a density of 1.10 g/mL.

Question 4: In a solution, the grams of solute should always be less than the grams of solvent. Assuming you have prepared the solutions above (using 1 kg of H_2O) so that they have a freezing point of -10.49 °C, in which solution have the roles of the solute and solvent been reversed? Suggest how the reversal of the roles of the solute and solvent would impact your conclusions about that solution.

Help Session 10: Thermodynamic Moles of Reaction

Study Skills Activity: The example below was used to demonstrate the concept of moles of reaction.

If 0.15 moles of *B* react with 0.30 moles of *A*, how many moles of reaction occur?

$$3A + B \rightarrow 3A_3B$$

- If the reaction occurred once, you would need three molecules of *A* and one molecule of *B*.
- If the reaction occurred ten times you would need thirty molecules of *A* and ten molecules of *B.*
- If the reaction occurred one mole of times you would need 3 x (6.022×10^{23}) molecules of *A* and 6.022×10^{23} molecules of *B*, or you would need three moles of *A* and one mole of *B* for one mole of reaction to occur

Identify the limiting reactant:

$$(0.30 \text{ mol A})\left(\frac{1 \text{ mol rxn}}{3 \text{ mol A}}\right) = 0.10 \text{ mol rxn}$$

$$(0.15 \text{ mol B})\left(\frac{1 \text{ mol rxn}}{1 \text{ mol B}}\right) = 0.45 \text{ mol rxn}$$

Substance *A* is limiting, and 0.10 moles of reaction occurred.

Course Content Activity: Students worked in groups of three to four on the following problems.

1. If 20.0 g of S reacts with 25.0 g of O_2 according to the balanced equation below. How many moles of reaction occurred, and what is the total amount of heat released by the reaction?

   $2S + 3O_2 \rightarrow 2SO_3 + 751 kJ/mol$

2. 25.0 mL of 0.100 *M* hydrochloric acid and barium hydroxide are reacted in a coffee cup calorimeter, with heat capacity of 21.6 J/°C. Both of the solutions are initially at 20.0 °C and a have a specific heat of 4.184 J/g°C. After the reaction is complete, the resulting solution has a temperature of 23.7 °C and a density of 1.05 g/mL. How much heat is generated by the reaction? How many moles of reaction have occurred? What is the heat of neutralization for this reaction?

3. 25.0 mL of 0.100 *M* sulfuric acid and sodium hydroxide are reacted in a coffee cup calorimeter, with heat capacity of 21.6 J/°C. Both solutions are initially at 25.0 °C and a have a specific heat of 4.184 J/g°C. After the reaction is complete, the resulting solution has a temperature of 28.5 °C and a density of 1.10 g/mL. How much heat is generated by the reaction? How many moles of reaction have occurred? What is the heat of neutralization for this reaction?

Help Session 11: Equilibrium and Percent Ionization

Study Skills Activity**:** Reviewed strategies related to taking multiple-choice exams.

Course Content Activity: Students worked in groups of three or four on the following problems.

1. Calculate the pH and the percent ionization of a 0.200 *M* weak acid (K_a = 1.50 x 10^{-6}) solution.

2. Calculate the pH and the percent ionization of a 0.210 *M* weak base (K_b = 1.3 x 10^{-3}) solution.

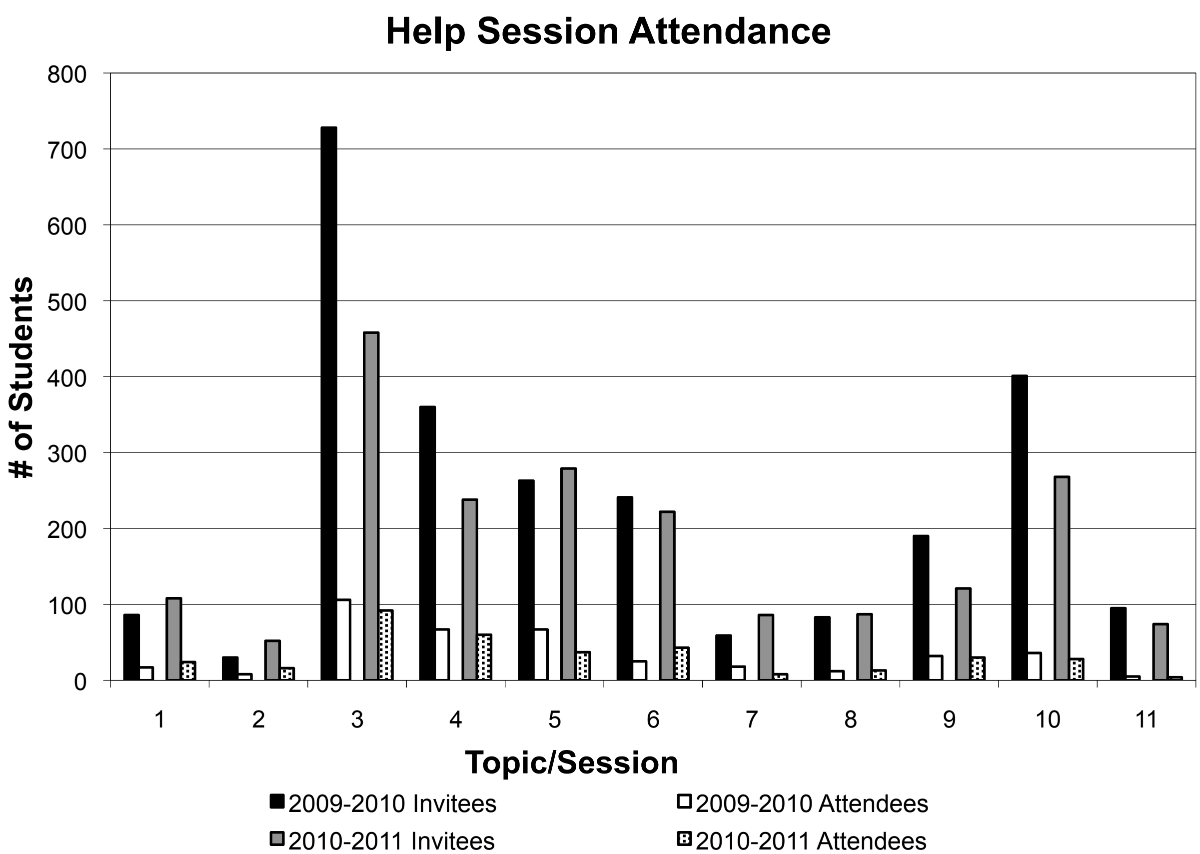
3. A 0.170 *M* weak acid is 1.07 % ionized. What are the K_a, the H^+ concentration, and the pH of the solution?

4. What is the initial concentration of a weak base (K_b = 2.4 x 10^{-5}) in a solution with a pH = 9.75? What is the percent ionization of the weak base?

Results and Discussion

Figure 3.2 summarizes the help session attendance of at-risk students during the 2009-2010 and 2010-2011 academic years.

Figure 3.2: Help session attendance of at-risk students during the 2009-2010 and 2010-2011 academic years.



During the 2009-2010 academic year 2,536 invites were sent to at-risk students, and 393 (15.5 %) of those invites resulted in attendance at one of the eleven help sessions.

During the 2010-2011 academic year 1,993 invites were sent to at-risk students, and 355 (17.8 %) of those invites resulted in attendance at one of the eleven help sessions. Note students can be invited to as many as eleven help sessions per academic year, which accounts for the large number of invites sent. The slight increase in attendance at help sessions during the 2010-2011 academic year is attributed to course instructors emphasizing the importance of student attendance more frequently. During the two-year span of the project 16.5 % of the invites sent to students who were identified as at-risk actually resulted in help session attendance.

To further validate the original definition of at-risk students, and to ensure that low help session attendance was not related to a poor definition of at-risk students, the performance on subsequent relevant test questions of invited (at-risk) students was compared to students who were not invited to each help session. The performance on subsequent relevant test questions of invited and non-invited students is summarized in table 3.5.

Table 3.5: A comparison of the performance of invited (at-risk) and non-invited students from 2009-2010 and 2010-2011 academic years on subsequent test questions about the eleven key chemistry topics.

Topic	% Chance of At-risk vs. Non-invited Students in 2009-2010 Correctly Answering at Least ½ the Relevant Test Questions	% Chance of At-risk vs. Non-invited Students in 2010-2011 Correctly Answering at Least ½ the Relevant Test Questions
1	31.2	**38.9**
2	-12.6	**58.9**
3	**43.1**	**53.0**
4	**25.4**	**27.6**
5	10.6	**50.1**
6	**47.3**	**67.6**
7	**47.9**	**37.8**
8	32.0	**45.8**
9	**40.1**	**56.3**
10	**43.8**	**40.3**
11	**32.6**	**58.8**

* Numbers in bold are significantly different ($p < 0.10$).

The data indicate that in 2009-2010 at-risk students had a significantly lower probability of correctly answering at least half of the relevant test questions when compared to non-invited students in seven out of eleven cases. During the 2010-2011 academic year at-risk students had a significantly lower probability of answering at least half of the relevant test questions when compared to non-invited students in all eleven cases. The probabilities were obtained using a logistical regression analysis, since the sample distributions were not uniform. This data further validates the fact that at-risk students are at a significantly higher risk of poor performance on subsequent tests. The newly developed definition of at-risk students (students who incorrectly answer all of the homework questions related to one of the key topics) is sound. The additional instruction these students receive at a help session is aimed at increasing their chances of success on subsequent exams.

Figure 3.3 summarizes the impact help sessions had on student performance. The figure displays the percent of at-risk students that incorrectly answered at least half the test questions related to each topic after having the option to attend a help session about that topic. The data for each topic are broken down by year. Each year is further broken down into all at-risk (invited) students, at-risk students who attended the help session about that topic, and at-risk students who did not attend the help session about that topic.

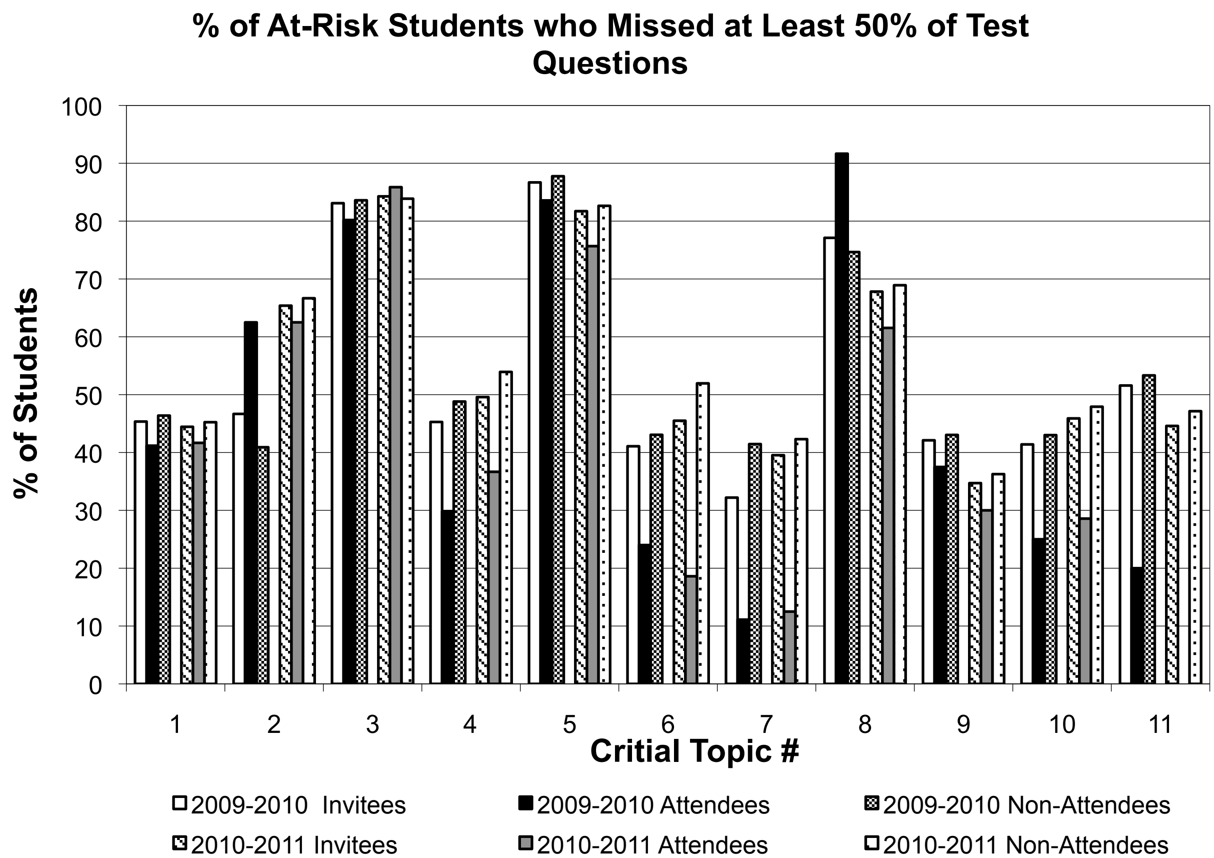


Figure 3.3: The percent of at-risk students who incorrectly answered at least half of the relevant test questions.

A quick survey of figure 3.3 reveals that help session attendees missed fewer questions than non-attendees in a majority of cases over the two-year period. To evaluate whether performance gains of attendees were significant, a logistical regression analysis was performed. The analysis compared the percent chance of attendees versus non-attendees correctly answering at least half of the relevant test questions for each topic. The results of the analysis are presented in table 3.6.

Table 3.6: A comparison of the performance of attendee and non-attendee at-risk students from 2009-2010 and 2010-2011 academic years on subsequent test questions about the eleven key chemistry topics.

Topic	% Chance of Attendee vs. Non-Attendee At-risk Students in 2009-2010 Correctly Answering at Least ½ the Relevant Test Questions	% Chance of Attendee vs. Non-Attendee At-risk Students in 2010-2011 Correctly Answering at Least ½ the Relevant Test Questions
1	29.1	35.3
2	-71.7	20.0
3	25.0	-15.4
4	**121.4**	**72.7**
5	24.3	36.1
6	**139.7**	**325.6**
7	**475.5**	456.2
8	-72.6	36.0
9	27.1	36.6
10	**142.6**	**128.8**
11	356.7	N/A**

* Numbers in bold are significantly different ($p < 0.10$).
** Help session attendance to small for valid statistical analysis

In a majority of the cases presented in table 3.6 attendees performance was not significantly different when compared to the performance of non-attendees. Students who attended help session four (interpretation of quantum numbers), help session seven (Lewis acid and base theory), and help session ten (thermodynamic moles of reaction) are statistically very likely to outperform, on the subsequent exam, their counterparts who choose not to attend the session.

The statistical analysis of the performance of attendees versus non-attendees is complicated by low help session attendance. A brief statistical power analysis revealed that in most cases at least forty at-risk students would have to attend a help session for statistically significant results to be seen. During the two-year period of the project, only six help sessions had an attendance greater than forty at-risk students. In three of those six cases, attendees experienced statistically significant gains in performance compared to non-attendees. The lack of gain in the other three sections can be attributed to many factors, including but not limited too, the way in which the material was presented in the help session.

The complications with low help session attendance and attendee performance are further illustrated when you examine data related to topic eleven (equilibrium and percent ionization). Over the two-year period 169 students were invited to help sessions about topic eleven. Nine of the 169 students invited attended a help session. All nine of the students who attended a help session on topic eleven answered at least half of the relevant test questions correctly. Eight out of the nine students answered all of the relevant test questions correctly. The statistical analysis of this date yielded little meaningful information about the performance of attendees versus non-attendees because of the small number of attendees. Similar patterns can be seen in a majority of the help sessions. Because of the low attendance at help sessions, figure 3.3 may actually provide a better description of the improvement in performance experienced by attendees.

A closer examination of figure 3.3 reveals that students who attended help sessions for topics two (unit conversions) and eight (intramolecular versus intermolecular forces) during the 2009-2010 academic year actually performed worse on subsequent relevant test questions than non-attendees. The performance deficit was not statistically significant. The poor performance of attendees on subsequent relevant test questions was either due to random chance or related to the way material was presented in those help sessions. In an effort to reverse the trend in the 2010-2011 academic year, the lesson plans for both help sessions where reworked. The revamp of the lesson plans resulted in a reversal of the performance trend during the 2010-2011 academic year. Figure 3.3 clearly shows that during the 2010-2011 academic year attendees performed better on subsequent relevant test questions than non-attendees. The performance gains in the 2010-2011 academic year were not statistically significant, but they do represent a more desirable outcome. This outcome could again be due to random chance. It is certain that the way in which material is presented in the help session has the potential to have a large impact on attendees' performance.

At the conclusion of every help session all students that were present were asked to use their clickers to respond to two questions. Question one asked the students if they found the session helpful. Of the 1,308 students surveyed 95 % responded yes, 2 % responded no, and 6 % responded they were unsure. Question two asked the students if they would attend a future help session. Of the 1,295 students surveyed 85 % responded yes, 0.2 % said no, 1 % said unsure, and 13.8 % said it depends on the topic of the session. Note that institutional review board policies prohibit restricting access to additional instruction, which means student opinion data includes both at-risk and other students. Additionally not all students answered every survey question. Overall the students have very positive opinions of the help sessions.

Future Directions

The current data leaves little doubt that at-risk students who attend help sessions will perform better on key topics on subsequent tests. The goal of future work must be to increase help session attendance. Two probable solutions to the attendance problem exist. One solution involves implementing mandatory quizzes as a portion of the students' course grades. Each mandatory quiz would cover information from one of the eleven key topics. Students who attend the help sessions would have the option to complete the quizzes at the end of the help sessions as opposed to in class. Theoretically, students who attend the help sessions would perform better on the quizzes, which would provide them motivation to attend future sessions. The second solution would be to cover help session material in some form of a mandatory recitation section. These sections could either be added into the course during a separate meeting time, or an hour of lab time could be used for the recitation section. To insure similar performance results, recitation leaders would have to be properly trained and closely monitored.

Once the attendance at help sessions increases, which will improve the statistical validity of the results, the research focus can shift to finding the most effective way to present material related to the eleven key topics. Reworking the lesson plans for help session two and eight in this study was shown to have a tremendous impact on student learning. The lesson plans used in this study are grounded in cooperative learning theory. Using additional theoretical frameworks to construct the lessons has the potential to have an even larger impact on student performance.

Conclusions

This study has resulted in the development of a rigorous definition of students who are at-risk of performing poorly on subsequent tests because of their lack of understanding of one of the eleven key general chemistry concepts at UGA. At-risk students who accepted an invitation to attend a help session geared towards increasing their knowledge about one of key topics consistently outperformed at-risk students who chose not to attend. An overwhelming majority of attendees found the help sessions useful and would attend a future help session if they were invited. In-time remedial help sessions can be an excellent way to have an immediate positive impact on student performance.

Chapter 4: Implementation and Assessment of Cognitive Load Theory (CLT) Based Questions in an Electronic Homework and Testing System

CLT and Human Cognitive Architecture

Cognitive load is a measure of the demands put on working memory when learning a particular task [12]. Cognitive Load Theory (CLT) emphasizes the interactions between the structure of information to be acquired and human cognition in an effort to guide instructional design [13]. The initial development of CLT occurred in the early 1980s [13]. By the year 2000, CLT had become one of the premiere theories of human cognition. Effective instructional designs must take into account, and make effective use of, limited human cognitive resources while promoting learning [12]. CLT has been successfully implemented in instruction of statistics, physics, and engineering, but until now it has not been a driving force in chemistry instructional design [12]. In each of the previous implementations of CLT, students have been shown to spend less time, and exert less mental effort, to achieve superior knowledge retention and transfer measures [12]. Successful implementations have considered important learner variables such as age, spatial ability, and prior knowledge. Additionally, these implementations have accounted for the complexity, organization, and presentation of the information to be learned [12]. It is important to understand the basics of human cognitive architecture before elaborating on the tenants of CLT.

Human cognitive architecture is divided between short-term, working, and long-term memory [12-16]. We are only conscience of the items stored in working memory

[15]. Information enters working memory from sensory memory or long-term memory [15]. Working memory can hold a maximum of seven new items, which enter via sensory memory, at any one time [12-16]. These new items are held in working memory for an average of twenty seconds unless they are rehearsed multiple times. There is no limit to the amount of information that can enter working memory from long-term memory [13, 15]. Working memory is limited because individual information elements increase linearly, but the number of ways in which informational elements can be combined and transferred to long-term memory increases exponentially [13]. Successful instructional designs must address, and work to maximize, the limitations of working memory [15].

An unlimited amount of permanent information is stored in long-term memory in the form of schemata [12-16]. A schema can be thought of as an interconnected web of information useful in a problem-solving situation. Schemata that are used multiple times in various situations become automated [13]. The use of an automated schema is an unconscious process, which means it utilizes no working memory [15]. In order for permanent learning (i.e. knowledge retention and transfer) to occur, alterations must be made to schemata in long-term memory [15]. Alterations to long-term memory must be small, sometimes random, modifications that prove effective in multiple problem-solving situations [15]. Ultimately, effective instructional design must target the construction and automation of schema while remaining within the confines of working memory [12, 13, 15].

The cognitive load of a particular task must be less than the working memory resources available to process that load for meaningful learning to occur [12]. CLT attempts to reduce working memory load to maximize meaningful learning [12, 14]. There are three types of cognitive load, intrinsic, extraneous, and germane [12-14, 39].

Intrinsic load results from a combination of the complexity of the information to be processed and the learner's previous knowledge [12-14, 39, 40]. In other words information with four or five interrelated items generates more load than information with two or three interrelated items. Since it is assumed that there are no means for manipulating the prior knowledge of a learner, intrinsic load is difficult to minimize. The minimization requires separating complex information into individual elements for the learner [13-15]. Once the learner is comfortable with all of the elements, they are recombined so the learner can carefully evaluate the information as a whole again [13-15]. This process temporarily decreases the knowledge the learner can gain, but the knowledge potential is restored when elements are recombined [13-15].

Extraneous load results from poor instructional design [12-14, 39, 40]. For example a figure that requires a novice learner to interpret text and an image separately has very high extraneous load. The extraneous load would decrease, for a novice learner, if the text were integrated into the figure. Extraneous load is the easiest form of load to manipulate. The extent to which extraneous load must be minimized depends on the learner's prior knowledge. The majority of CLT studies focus on minimizing extraneous load in effort to maximize learning [16].

The final type of cognitive load is germane load. Germane load results from the construction and automation of schema [12-14, 39, 40]. In other words germane load is load that results from permanent learning. The three types of load are additive [13, 14]. Minimizing extraneous and intrinsic load should maximize germane load. Studies have shown that this is only true if learners remain motivated to construct and utilize schema [13]. Learners remain motivated if there is slight variability in the problems they are asked to solve [13]. Additionally, asking learners to think in a metacognitive manner about their problem solving process has been shown to promote schema construction and automation [13]. The automation of schema, which makes the utilization of the schema an unconscious process, removes the burden that information previously posed on working memory and indirectly reduces cognitive load [14].

The major focus of this study was the minimization of extraneous load to promote knowledge retention through problem solving. Prior knowledge dictates how a learner approaches a problem-solving situation [14, 15, 40]. Novices possess fragmented prior knowledge, which generally leads them to provide a superficial solution to the problem [14]. The solution is usually generated using a "means-end" analysis followed by the generation of random possible responses, which are tested for effectiveness [15, 40]. Means-end analysis involves isolating the given information and then determining a method of using that information to reach the goal set out by the problem. Fragmented prior knowledge and "means-end" analysis imposes a large load on working memory, which means novices are very susceptible to cognitive overload [14, 40]. Experts utilize relevant schema as a "road map" to solve problems [14]. The use of schema generates little if any load on working memory, especially if the schema is automated. Experts tend to provide detailed and complete solutions to problems [14]. Effective instructional designs that are based on problem solving must take into account the prior knowledge of the learner [15]. Additionally, these designs must adapt to the changing level of expertise of a learner over time [15].

The adaptive nature of instructional design is necessary in order to combat the expertise reversal effect [15]. The expertise reversal effect states that certain minimizations of extraneous load, which were helpful to novice learners, may actually present more advanced learners with redundant information that increases cognitive load [13, 15, 16]. This increase in cognitive load makes it difficult for advanced learners to process new information. For example, novice learners tend to experience a lower cognitive load when captions are integrated into figures. More advanced learners are capable of interpreting the figure without the integrated text. For these learners the integrated text provides additional cognitive load resulting in negative impacts on learning. Many instructional design methods have been developed to insure adaptive learning while combating the expertise reversal effect.

The problem solving based instructional design approach modeled in this study begins by allowing the learner to study a fully worked out example problem. The example clearly displays and explains the steps necessary to reach a solution [12, 13, 15, 40-42]. The example decreases extraneous load by providing a schema design the learner can use to solve the problem [12, 13, 40, 42]. The learner is then transitioned to a series of completion problems, which are intended to force the learner to apply the concepts from the worked out example. Each completion problem asks the learner to answer some portion of the original question [12, 13, 15, 40-42]. The first completion problem asks the learner to complete the final step in the solution, while the remainder of the solution is provided. The second completion problem asks the learner to complete the last two steps of the solution and the rest of the solution is provided. This process repeats until the learner is left to complete the problem without any assistance.

The process of requiring the learner to complete additional step(s) is known as static fading [40-42]. The rate of the fading process depends on the learner's prior knowledge, and adjusting the fading rate helps to combat the expertise reversal effect [41]. Reducing a multistep problem into single steps decreases extraneous load [12, 13, 40-42]. Static fading can take two forms, forward (removing assistance for the first, then second, then third, etc… steps) or backward (removing assistance for the last, then second last, then third last, etc... steps) [40-42]. A static backward fading approach with a rate of one step per problem was used in this study. The completion of a problem without any further assistance is referred to as independent problem solving [12, 13, 15, 40-42]. Independent problem solving allows the learner to utilize the newly developing schema in slightly varied problem solving situations. The combination of decreasing extraneous load and the development of schema indicate that this instructional design strategy has the potential to promote student learning. The following study was designed to measure the impact implementing this instruction design strategy had on student performance.

Experimental Methods

The general chemistry sequence at the University of Georgia (UGA) is two semesters. All general chemistry students at UGA complete ten electronic homework assignments and four exams each semester. Three of the exams are administered electronically and the fourth exam is a paper and pencil American Chemical Society (ACS) standardized exam. All of the electronic homework assignments and tests are delivered via our electronic homework and testing system, JExam. A majority of the homework and test questions contain text, which means it is critical to understand the specific effects of text presentation on cognitive load.

Learning from text generally involves large cognitive loads [43]. Text that is presented in segments, which require the learner to advance through several screens before reading all of the information, generates high extraneous load [43]. Text should be presented all on the same screen, in its entirety, in order to minimize extraneous load [43]. Additionally, learners should be able to read through and review text at their own pace. Self-paced reading has been shown to minimize extraneous load and help with schema construction [43]. Any examples used in the text should be consistent throughout the entire text [43]. Introducing additional examples requires additional cognitive resources to process, which increases extraneous load [43]. All of the problems presented in this study permit the students to proceed through the text at their own pace, present the entire text on one screen, and utilize similar examples.

For this pilot study eight electronic homework questions were converted to CLT based questions that incorporated the worked example to completion problems to independent problem solving instructional design. During this process one standard homework problem, with a logical three-step solution, was split into four problems. The approach utilized a backward static fading design with a rate of one step per problem. The first problem was a fully worked out example. The example presented the question and the solution broken into three logical steps. The second problem was the first completion problem. This problem displayed the question and the first two steps of the solution. The student was responsible for providing the solution for step three. The third problem was the second completion problem. This problem displayed the question and the first step of the solution. The student had to provide the answers for steps two and three. The fourth and final problem was an independent problem solving exercise. This exercise displayed the question and expected the student to work through all of the solution steps they had learned to input the correct final answer. The process of converting a regular electronic homework question to an electronic CLT based problem is outlined in figures 4.1 through 4.5. Figure 4.1 contains the original electronic homework question. Figure 4.2 contains the fully worked out example. Figures 4.3 and 4.4 contain completion problem one and two respectively. Figure 4.5 contains the independent problem solving exercise. Note that all problems are similar in an effort to maintain the same example thus reducing cognitive load.

Original Question:

Rank the following in order of increasing (weakest to strongest) conjugate base strength.

F^-, I^-, Cl^-

Figure 4.1: An original electronic homework question prior to conversion to a CLT based question.

Worked Out Example (Question 1):

Question: Rank the following in order of increasing (weakest to strongest) conjugate base strength.

F^-, I^-, Cl^-

Solution Step 1: We do not know how to arrange bases by strength directly, so must determine the conjugate acid of each base. This done by adding an H+ to each base. The conjugate acid of each base is listed below.

The conjugate acid of F^- is HF
The conjugate acid of I^- is HI
The conjugate acid of Cl^- is HCl

Step 2: We must now arrange the conjugate acids in order of increasing acid strength. Since all of the acids listed above are binary they are ranked in strength based on the size of their anions. Each anion has a parent element that you can find on the periodic table. The closer to the bottom and further left on the periodic table that parent element is, the larger it is. We must first identify what the anion is in each acid, and what period its parent element is located in on the periodic table. We do not have to worry about the group number because all of the parent elements of these anions are in the same in group on the periodic table. The correct ranking of the conjugate acids in order of increasing acid strength is shown below.

HF < HCl < HI

Step 3: We know that the stronger the acid the weaker its conjugate base, and the weaker an acid the stronger its conjugate base. In other words the strongest acid has the weakest conjugate base, and the weakest acid has the strongest conjugate base. Below is the correct ranking, in increasing order, of the conjugate bases listed above.

$I^- < Cl^- < F^-$

Figure 4.2: A fully worked out example for a CLT based question with a three-step solution.

Question 2:

Question: Rank the following in order of increasing (weakest to strongest) conjugate base strength.

OH^-, HTe^-, HS^-

Solution Step 1: We do not know how to arrange bases by strength directly, so must determine the conjugate acid of each base. This done by adding an H+ to each base. The conjugate acid of each base is listed below.

The conjugate acid of OH^- is H_2O
The conjugate acid of HTe^- is H_2Te
The conjugate base of HS^- is H_2S

Step 2: We must now arrange the conjugate acids in order of increasing acid strength. Since all of the acids listed above are binary they are ranked in strength based on the size of their anions. Each anion has a parent element that you can find on the periodic table. The closer to the bottom and further left on the periodic table that parent element is, the larger it is. We must first identify what the anion is in each acid, and what period its parent element is located in on the periodic table. We do not have to worry about the group number because all of the parent elements of these anions are in the same in group on the periodic table. The correct ranking of the conjugate acids in order of increasing acid strength is shown below.

$H_2O < H_2S < H_2Te$

Student Responsibility: Rank the conjugate bases in the example above in order of increasing (weakest to strongest) conjugate base strength.

Figure 4.3: The first completion problem for a CLT based question with a three-step solution.

Question 3:

Question: Rank the following in order of increasing (weakest to strongest) conjugate base strength.

OH^-, HTe^-, HSe^-

Solution Step 1: We do not know how to arrange bases by strength directly, so must determine the conjugate acid of each base. This done by adding an H+ to each base. The conjugate acid of each base is listed below.

The conjugate acid of OH^- is H_2O
The conjugate acid of HTe^- is H_2Te
The conjugate acid of HSe^- is H_2Se

Student Responsibility: Rank the conjugate acids from the example above in order of increasing acid strength. Rank the conjugate bases in the example above in order of increasing (weakest to strongest) conjugate base strength.

Figure 4.4: The second completion problem for a CLT based question with a three-step solution.

Question 4:

Question: Rank the following in order of increasing (weakest to strongest) conjugate base strength.

F^-, Br^-, Cl^-

Figure 4.5: An independent problem solving exercise that concludes a CLT based question with a three-step solution.

Eight homework questions, four from first semester and four from second semester general chemistry, were chosen for the pilot study of this instructional design approach. Each question was converted into a four-question sequence similar to the sequence outlined in figures 4.1 through 4.5. The topics these questions addressed are shown in table 4.1. These topics were chosen because item response theory (IRT) analysis of general chemistry exams from the fall 2001 through spring 2009 revealed that these topics consistently ranged from moderately to extremely difficult for students.

Table 4.1: Topics of the eight homework questions that were converted to CLT based questions.

Topic #	Semester	Topic
1	1	Number of ions per formula unit
2	1	Complex dilution calculations
3	1	Interpreting first ionization energy
4	1	Inorganic nomenclature
5	2	Acid and base strength
6	2	Unit cell calculations
7	2	Interpreting vapor pressure lowering
8	2	Interpreting images to determine when equilibrium was established

In an effort to measure the effectiveness of this instruction design approach, similar test questions were placed on the exam immediately following the homework assignment where a CLT based question appeared. The test questions were similar in an effort to measure student knowledge retention. All exam questions were analyzed using a modified three-parameter IRT analysis. Details concerning the specifics of a modified three-parameter analysis can be found in chapter 5 of this document or in information published by Baker and de Ayala [17, 18]. As a result of the IRT analysis, every question is assigned an item difficulty. A comparison of the specific test question difficulties before and after the CLT based instructional innovation was used to determine the effectiveness of the instructional design approach.

The same test questions that were used to measure knowledge retention from the CLT instructional innovation were administered to students a year before the innovation. These students experienced the standard electronic homework questions discussed above. The difficulties of the test questions were determined on that year's metric using IRT analysis. The test question difficulties were then determined again after students the following year had completed CLT based electronic homework questions. Note that these question difficulties were on a different metric from the original test question difficulties. The differences in the difficulties should indicate how effective the CLT instructional design innovation was. A decrease in question difficulty indicates an increase in student knowledge retention. A complication arises in the comparison of the difficulties because they were analyzed on different metrics. According to IRT theory different metrics have different origins, which means a direct comparison of the difficulties is not possible. Instead difficulties must be transformed onto the same metric. Details of how the metric transformation using total characteristic function equating was carried out can be found in chapter 5 of this document as well as in information published by Stocking and Lord [44]. The program IRTEQ was used to carry out the Stocking and Lord equating process [45]. After the question difficulties were equated the effectiveness of the CLT based instruction design approach was evaluated using the difference in the equated test question difficulties.

Results and Discussion

Figure 4.6 summarizes the equated test question IRT difficulties before and after the implementation of the CLT based homework questions. On seven out of the eight topics the difficulty of the questions decreased significantly. Note that a lower difficulty value indicates a greater understanding of the material by the students.

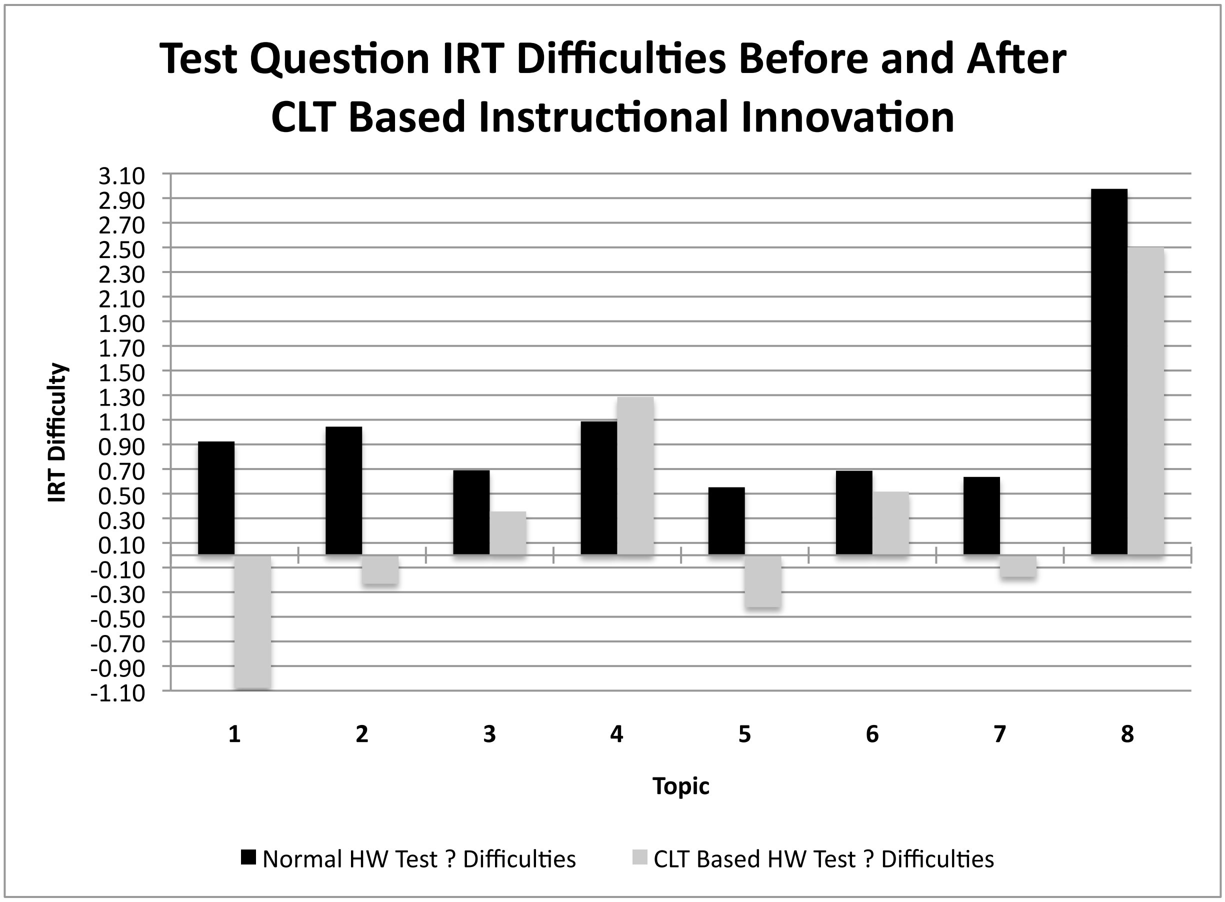


Figure 4.6: Test question difficulties before and after the implementation of CLT based homework questions.

In topic 4, which is inorganic nomenclature, there was a significant increase in the difficulty of the test question after the CLT based homework questions were implemented. CLT based homework questions should assist the students in constructing the schema necessary to systematically name compounds. Even with this schema in place, a great deal of memorization in the area of polyatomic ion formulas is still required to name inorganic compounds correctly. The large amount of memorization required, because this particular test question contained polyatomic ions, presumably increased the load on working memory. The large increase in cognitive load as a result of required memorization and likely differences in student prior knowledge from year to year are possibly to blame for the increase in question difficulty. To verify this, future work should examine student responses to questions that involve nomenclature of inorganic compounds without polyatomic ions, while more effectively accounting for student prior knowledge. Those responses could then be compared to nomenclature questions where polyatomic ions are involved to determine the impact memorization of polyatomic ions and prior knowledge levels have on cognitive load.

Table 4.2 presents the numeric values of the equated test question difficulties before and after the implementation of the CLT based homework questions, the change in test question difficulties, and the change in the percent chance of a student correctly answering the test question about that topic.

Table 4.2: Numeric values of test question difficulties before and after CLT based homework questions were implemented.

Topic	1	2	3	4	5	6	7	8
Normal HW Test Question Difficulties	0.924	1.044	0.690	1.087	0.552	0.686	0.636	2.975
CLT Based HW Test Question Difficulties	-1.077	-0.232	0.356	1.286	-0.421	0.517	-0.175	2.501
Change in Test Question Difficulties	**-2.018**	**-1.333**	**-0.419**	**0.071**	**-0.973**	**-0.169**	**-0.811**	**-0.474**
Change in % Change of Correct Response	33.636	22.209	6.978	-1.184	16.220	2.825	13.514	7.901
# of Students	1810	1810	1810	1810	1745	1745	1745	1745

* Numbers in bold show a significant difference ($p < 0.01$).

Based on a two-tailed t-test, the change in test question difficulty for each topic is significantly different at the 99 % confidence interval. In other words, on seven out of the eight topics there was a significant increase in student knowledge retention/learning. The significant decrease in student learning, which occurred on topic four, has been discussed above. The bivariate plot generated during IRT analysis indicates a decrease of 0.06 difficulty units corresponds to an increase of 1.00 % in the probability of a correct student response to test questions about that topic. Test questions about number ions per formula unit, complex dilution calculations, acid base strength, and interpreting vapor pressure lowering experienced an increase of greater than 10 % in the probability of a correct student response. Using most standard grading scales an increase of 10 % corresponds to an increase of one letter grade.

The data presented above leave little doubt that this CLT instructional design approach, which changes standard homework questions to worked out examples, completion problems, and independent problem solving exercises, increases knowledge retention for these chemistry topics. This strategy is likely more effective on problems that do not require a large amount of memorization, in addition to schema construction, to successfully answer. More research is needed to verify this claim, and even more additional research, some of which is outlined below, is needed before this instructional design approach can be declared maximally useful for the chemistry domain.

Future Work

To test the effectiveness of CLT based instructional design across the entire chemistry domain, a wider variety of question topics must be converted to the CLT format and analyzed. The pilot study suggests that as long as memorization requirements are kept to a minimum, chemistry knowledge retention should increase. The topics selected for analysis should also be from a wider range of difficulty levels. It could be argued that students have the most to learn from difficult topics, which may be why the performance gains in the pilot study were so large. Additional studies should examine this possibility

The static fading approach utilized to transition from completion problems to independent problem solving in this study yielded excellent results. Recent research studies have seen even larger performance gains when an adaptive fading approach is employed [40]. Adaptive fading uses the student's response to the current question to dictate what the next question for the student is [13, 40]. For example if a student is asked to provide the answer to step three of the solution, one of two possibilities will occur. If the student answers step three correctly, the next question will ask the student to answer steps two and three, provided a backward fading approach is employed. If the student answers step three incorrectly, the computer will display a worked out example that demonstrates the solution up through step three. The adaptive fading approach works to take into account the student's prior knowledge [13, 40]. Studies that have compared static to adaptive fading approaches report superior learning gains for the adaptive fading participants regardless of prior knowledge [40]. In an effort to continue to improve student performance gains, as well as incorporate the learners' ever changing prior knowledge, a CLT based adaptive fading instructional design approach should be developed and tested in chemistry electronic homework and testing systems.

This pilot study has assumed that the gains in student performance are a result of decreased cognitive load as opposed to some other variable, such as increased time on task. Though student performance has been directly correlated with the amount of cognitive load a learner experiences, it is not the most reliable measure of cognitive load [12]. Future studies should incorporate more accurate measures of load to insure that performance gains are a result of decreased cognitive load. There are both analytical and empirical techniques that can be used to measure cognitive load [12, 39]. Analytical techniques utilize mathematical models to determine the amount load an learner is experiencing [12, 39]. Empirical techniques rely on subjective measures of learner mental effort and perceived item difficulty to determine load [12, 39]. Empirical techniques are much more common in the literature. Though mental effort and difficulty ratings are subjective, they have been shown to be a strong indicator of cognitive load [12]. Regardless of the technique chosen, measures of cognitive load would help determine whether time on task or reduced cognitive load are responsible for the performance gains seen from these techniques.

Conclusions

This pilot study clearly demonstrates that CLT based instructional design approaches to problem solving have the potential to have a major impact on student performance in the chemistry domain. There is an abundance of future research work needed to quantify the breadth and depth of the impact CLT will have on the chemistry domain. These approaches are easy to implement in most electronic homework and testing environments. The most time consuming portion of the implementation is writing effective worked out examples, completion problems, and independent problem solving exercises. This study indicates that the time invested in writing these items and other research is sure to be rewarded with gains in student knowledge retention.

Chapter 5: IRT Equating: A Longitudinal Study of Student Performance

Introduction

To attract high quality students and operational funding academic departments must demonstrate that instructional innovations lead to improved student performance. Performance assessments are the primary means for gauging student understanding in most general chemistry programs. Longitudinal studies comparing student performance on similar exams frequently decide the effectiveness of instructional innovations and thus operational funding. This study was conducted using data from the Item Response Theory (IRT) analysis of test questions presented to students in general chemistry courses at the University of Georgia (UGA) from fall 2006 through spring 2011. A brief introduction to IRT is followed by a detailed description of the methods used in this analysis. Finally, the results of the analysis are presented.

Item Response Theory (IRT)

IRT is a means of analyzing tests based on student response patterns in an effort to determine the difficulty, discrimination, and guessing parameters for each test question [17, 18]. Each student is also assigned an ability based on their response pattern and probability of answering particular questions correctly [17, 18]. All of this information is combined into a total information curve for the exam. The total information curve is a visual indicator of the exam's reliability [17]. IRT is ideal for analyzing tests when the sample size exceeds 200 participants [17, 18]. The results obtained from IRT analysis are independent of the examinees because all parameters are estimated using a data model. This means that tests assessing the same topic should yield similar information regardless of the individuals completing the exam [17, 18]. IRT analysis provides a stark contrast to Classical Test Theory (CTT). CTT theory is best applied to small sample sizes. The responses of the top quartile versus the bottom quartile of students dictate most of the parameters determined by CTT. This means that two tests assessing the same topic, administered to two different populations, would yield very different results. IRT analysis provides a much more consistent data set for longitudinal studies.

Many publications in the modern literature provide details about IRT analysis. Baker and de Ayala are recommended to the IRT novice as an excellent starting point [17, 18]. A summary of the IRT analysis of dichotomous data is presented below. Only dichotomous data is discussed because all test question responses for this study were of a dichotomous, all right or all wrong, nature. Dichotomous student response data can be fit to one of three models to determine the question parameters and student abilities mentioned above [17, 18]. These three models are the one-parameter, two-parameter, and three-parameter models [17, 18].

The one-parameter model, also referred to as the Rasch model, utilizes the item difficulty parameter, *b*, to fit the data [17, 18]. The exact range of values of the difficulty parameter depends on the computer program carrying out the analysis. Questions having a higher difficulty parameter are more difficult to answer correctly [17, 18]. Students with abilities higher than the question's difficulty parameter have a high probability of correctly answering the question [17, 18]. Because the Rasch model does not allow much flexibility in fitting the data, it was not used in this analysis.

The two-parameter model combines the item difficulty parameter with the item discrimination parameter, *a* [17, 18]. The discrimination parameter indicates how well a particular question distinguishes between students of differing knowledge or ability levels [17, 18]. When $a = 0$, the question is likely to be correctly answered by students of all ability levels. For questions with large discrimination parameters, students with personal abilities greater than the question's difficulty parameter answer the question correctly, whereas students with abilities below the question's difficulty parameter are unable to answer the question correctly [17, 18]. The two-parameter model is ideal for questions where there is very little probability of guessing a correct answer (i.e. free response questions). Since none of the exams administered in the general chemistry program contained only free response questions, the two-parameter model was incorporated into a modified three-parameter approach, discussed below, for this analysis.

The three-parameter model adds the guessing parameter, *c*, to the difficulty and discrimination parameters [17, 18]. The guessing parameter indicates the probability with which a student can "guess" the correct answer to a question [17, 18]. Theoretically, $c = 0.25$ for a multiple-choice question that has four possible answers. For questions other than multiple-choice, the guessing parameter should approach zero. In current models the guessing parameter does not vary with student ability, which has the potential to cause model data fit problems [17]. The three-parameter model works best for the analysis of multiple-choice questions [17, 18]. Additionally, this model provides the most flexibility when attempting to model dichotomous student response data.

The tests analyzed for this study contained a combination of free response and multiple-choice questions. A modified three-parameter model was utilized to analyze the tests in order to provide maximum flexibility in fitting the student response data. The modification to the model occurred when the computer analyzed free response questions. In those cases, prompts in the program command file set the guessing parameter to zero. More information about the commands required to set the guessing parameter for individual questions can be found in de Ayala and du Toit [17, 46].

Mathematically IRT analysis constructs an item characteristic curve (ICC) for each question using the three parameters (*a*, *b*, and *c*) discussed above [17, 18]. The combination of these parameters determines the probability, $P(\Theta)$, that a student with ability, Θ, will correctly answer the question. This is accomplished by fitting the student response data to the *a*, *b*, and *c* parameters in equation 5.1, the IRT equation [17, 18].

$$P(\Theta) = c + (1 - c)\frac{1}{1 + e^{-a(\Theta - b)}} \qquad \text{equation 5.1}$$

An example of an ICC is shown in figure 5.1.

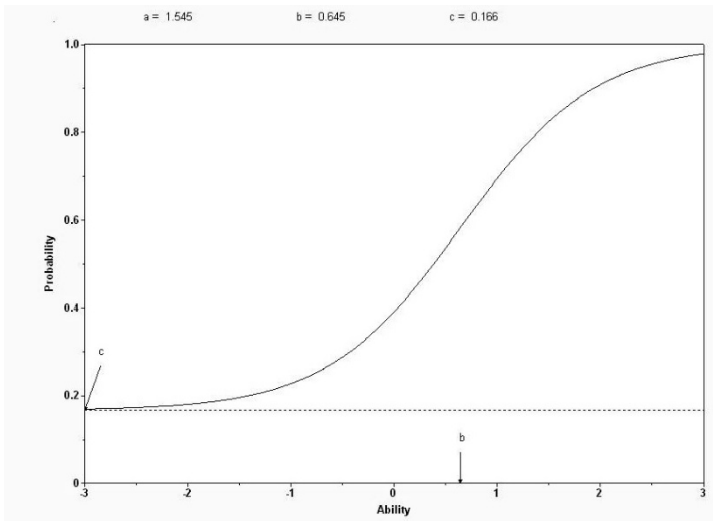


Figure 5.1: An example of an ICC for a question with a difficulty (b) 0.646, discrimination (a) of 1.546, and a guessing parameter (c) of 0.166.

IRT analysis was carried out using the BILOG-MG version 3.0 program [17, 46]. Item parameters and student abilities have a minimum of -4 (easy question) and a maximum of +4 (hard question) in this program [46]. Item parameters were determined using the marginal maximum likelihood estimate [17, 46]. After the item parameters were determined, student abilities were estimated using the Bayesian expected posteriori procedure [17, 46]. Data from 8,638 students insured a uniform distribution of student abilities was present when carrying out these procedures.

IRT Equating

One of the tenants of IRT analysis is its ability to provide similar results if similar exams are administered to similarly prepared populations. Unfortunately introductory college courses often have multiple instructors, and each instructor teaches material in a slightly different way. The order in which topics are taught and the teaching strategies used in a course tend to vary from year-to-year. All of these items, and other variables not mentioned here, lead to tests actually being analyzed on different ability and difficulty metrics [17]. For purposes of this study a metric refers to an individual year, because all tests from a single year were analyzed via IRT together. In other words, the numeric values of the item parameters and hence student ability levels vary depending on the metric [17, 44]. To compare how students' abilities vary year-to-year, it is necessary to place all items and students on the same metric [17]. The process of placing items from different metrics onto the same metric is know as linking [17]. The process of placing student abilities from different metrics onto the same metric is known as equating [17].

Since the probability in the equation 5.1 is a function of question difficulty and student ability, the origin and unit of measure of the ability and difficultly metric is undefined [17, 44]. That is to say that a probability function from one metric can be superimposed on a function from another metric via a linear transformation [17, 44].

The transformation from one metric to another will not change the probability of a correct response by a particular student [17, 44]. If b_{i1} is the item difficulty from the analysis of item *i* on metric 1, and b_{i2} is the difficulty of the same item from the analysis on metric 2, the value of b_{i2} transformed onto metric 1, b_{i2}^*, is given by equation 5.2 [44].

A and *B* are the linear transformation constants. Student abilities, Θ, must also undergo the same transformation, which is show in equation 5.3 [44].

Item discrimination parameters, *a*, are transformed according to equation 5.4 [44].

$$a_{i2}^* = \frac{a_{i2}}{A} \qquad \text{equation 5.4}$$

The guessing parameter, c, is on the probability metric, not the ability and difficulty metric, and therefore does not require transformation [44].

Transformation constants are determined by applying any one of the common IRT equating procedures [17]. Mean equating uses the mean item difficulty or student ability on each metric to determine the constants [17]. Linear equating aligns the means and standard deviations of the two metrics to obtain the constants [17]. Equipercentile equating aligns the means and standard deviations of the two metrics while maintaining the same overall distribution of difficulties and abilities [17]. All of these methods work equally well, but they fail to take into account all of the parameters of individual questions. These methods all introduce a large amount of error into the newly equated student abilities and item difficulties [17, 44]. A much more robust procedure for determining transformation constants involves total characteristic function (TCF) equating [17, 44].

TCF is a comparison of the total test score (or trait score) versus student ability [17]. Each student's trait score is computed by determining the probability of that particular student answering each question on the exam correctly [17]. There is a trait score for every student ability level. The probability is calculated using the IRT equation, equation 5.1. Since equation 5.1 incorporates all of the parameters of each question, the error present in equated difficulties and abilities is minimized [17, 44].

One of the most common variations of the TCF equating was introduced by Stocking and Lord [17, 44]. In this variation, parameters from common items on two different metrics are used to align the two TCFs [17, 44]. This alignment yields the transformation constants A and B when the difference in trait scores on the two metrics is minimized [17, 44]. The difference in trait scores on the two metrics is given by equation 5.5 [17, 44].

$$F = \frac{1}{N}\sum_{i=1}^{N}(T_i - T_i*)^2 \qquad \text{equation 5.5}$$

Where *N* is the number of participants, *T* is the trait score on metric one, and *T** is the trait score transformed from metric two to metric one. Equation 5.5 is said to be minimized when the partial derivatives of equation 5.5 with respect to *A* and *B* equal zero [17, 44]. Ultimately, *A* varies the slope of the TCF while *B* shifts the function along the continuum until the two TCF overlap as closely as possible [17, 44]. The Stocking and Lord approach was chosen for this analysis because of its ability to minimize error by incorporating item parameters from the numerous common items that existed in each metric.

Numerous computer programs are available to easily compute the Stocking and Lord transformation constants. For this analysis the freeware program IRTEQ was chosen [45]. The program requires two input files and one linking file [45]. The first input file contains the item parameters for the items on the metric to be equated to [45]. The second input file contains the item parameters from a different metric to be equated [45]. Both of the input files are formatted in .PAR format [45]. A sample input file for five items on a particular metric is shown in figure 5.2.

```
FA10SP11 TEST QUESTION EQUATING
11/05/2010 12:00:00 PM
FASP08     1   5   3   0   1
         5
GROUP 01
FASP1101   2001  0.69479  0.14065 -2.16745  0.49225  0.20799  0.09111
FASP1101   2002  0.83371  0.15271 -1.67336  0.38281  0.19163  0.08537
FASP1101   2003  1.07482  0.17612 -1.42810  0.28378  0.17432  0.07885
FASP1101   2004  0.79378  0.15663 -1.93593  0.43935  0.19714  0.08779
FASP1101   2005  0.56965  0.07638 -1.10110  0.17394  0.00100  0.00100
        0.00000  0.00000
        0.00000  0.00000
```

Figure 5.2: A sample IRTEQ item parameter input file for a five-item exam.

Lines one and two in the input file are a header [46]. Line three begins with the name of the exam/metric followed by the number of groups, 1, the number of items, 5, the IRT model used, 3-parameter, the number of subgroups, 0, and the multiple group code, 1 [46]. Line four and five repeat the total number of items and groups respectively [46]. Lines six through ten list the individual items and their parameters [46]. Columns one and two identify the test name and item number. Columns three and four are the item discrimination parameter and standard error. Columns five and six are the item difficulty parameter and standard error. Columns seven and eight are the item guessing parameter and standard error. The third file required for the analysis is a linking file, which tells the program what items are the same on both metrics [45]. The parameters of the common items are used to equate the TCFs. As a result of the equating process, the transformation constants *A* and *B* are determined. Using the transformation constants, all of the student abilities were placed on the same metric. The average student ability for each year was then calculated.

To validate the findings of the Stocking and Lord equating process, a simultaneous IRT analysis was performed. All student responses to the test questions administered between fall 2006 and spring 2011 were merged into a single IRT input file. The file was analyzed using the 3-parameter IRT model. Placing all of the data in one file and performing one analysis places all of the item difficulties and student abilities on the same metric [17]. This process is only successful if enough exam questions have been utilized multiple times during the duration of the sampling period [17]. After the analysis was completed, the student abilities were separated into their original year/metric, and the average student ability of each year/metric was calculated.

To yield meaningful results both the Stocking and Lord IRT equating approach and simultaneous IRT analysis require common anchor items to be present on multiple metrics [17]. Anchor items are items that appear in exactly the same form year after year. Anchor items must have a wide range of difficulties and make up at least 15 % of the items on any one metric [17]. Anchor items can be placed randomly amongst all of the test questions, internal items, or they can be placed at the end of the exam, external items [17]. External items are problematic because the examinee may suffer from fatigue, which may alter their response pattern and hence the item parameters [17]. All of the anchor items used during this analysis were internal in nature. IRT analysis has been performed on all exams administered to general chemistry students at UGA since fall 2001. Only the exams administered between fall 2006 and spring 2011 had at least 15 % of their items in common. The anchor items in these exams made it possible to carry out the Stocking and Lord IRT equating analysis as well as the simultaneous IRT analysis. The results of this analysis are presented below along with a brief discussion of the trend in student abilities over the past five years.

Results

An analysis of the total information curves for the exams administered in the 2006-2007, 2007-2008, 2008-2009, 2009-2010, and 2010-2011 academic years revealed that similar amounts of information were available about the students from each year indicating that the exams from all five academic years are assessing the same construct, chemistry, equally well. Item parameters and student abilities could be equated to any of these metrics. For this analysis all of the item parameters were transformed onto the 2009-2010 metric using the Stocking and Lord procedure outlined above. Table 5.1 displays the total number of exam items administered each year, total number of items in common with the exams administered in the 2009-2010 year, the percent of common items, and the Stocking and Lord transformation constants necessary to transform the parameters from that year onto the 2009-2010 metric.

Table 5.1: The number of common items and transformation constants for exams from fall 2006 to spring 2011.

Academic Year	Total # of Test Questions	# of Common Questions with 2009-2010	% of Common Questions	*A* Equating Constant	*B* Equating Constant
‘06-‘07	619	95	15.35	0.951	-0.370
’07-‘08	538	118	21.93	1.089	-0.439
’08-‘09	547	262	47.90	1.001	-0.381
’09-‘10	483	483	100.00	N/A	N/A
’10-‘11	475	345	72.63	1.049	0.071

The transformation constants were then used to place the student abilities from each year onto the 2009-2010 metric. The average and standard deviation of the equated student abilities for each year were then calculated. This information is displayed in table 5.2. In an effort to validate the average student abilities, a simultaneous IRT analysis of all five years worth of data was carried out. At the conclusion of the analysis, the average and standard deviation of the simultaneously determined student abilities for each year were calculated. This information is also displayed in table 5.2.

Table 5.2: The average student abilities and standard deviations from the IRT equating analysis and simultaneous IRT analysis of exam data from fall 2006 to spring 2011.

Academic Year	Average Equated Student Ability	Stand. Dev.	Average Simultaneous Student Ability	Stand. Dev.
‘06-‘07	-0.429174	0.8982	-0.008448	0.9606
’07-‘08	-0.529033	1.0565	-0.008149	0.9959
’08-‘09	-0.461031	0.9619	-0.001231	0.9702
’09-‘10	-0.173992	0.8495	-0.000948	0.9703
’10-‘11	-0.031572	1.0197	-0.000963	0.9833

Both the equated and simultaneous average student abilities followed a similar trend, and therefore were assumed to be valid results. An ANOVA analysis of both the equated and simultaneously determined average student abilities indicated that there was no significant difference between any of the abilities.

A closer look at table 5.2 reveals that both the equated and simultaneous student abilities show an increasing trend from fall 2006 to spring 2011. The lack of statistical validation for this trend indicates that over a longer period of time this trend may continue, or it may actually appear as a flat line. Several more years of data collection are necessary to paint a clearer picture. Additional data may also make it possible to predict learning trends for future students. These trends are displayed more clearly in figures 5.3 and 5.4.

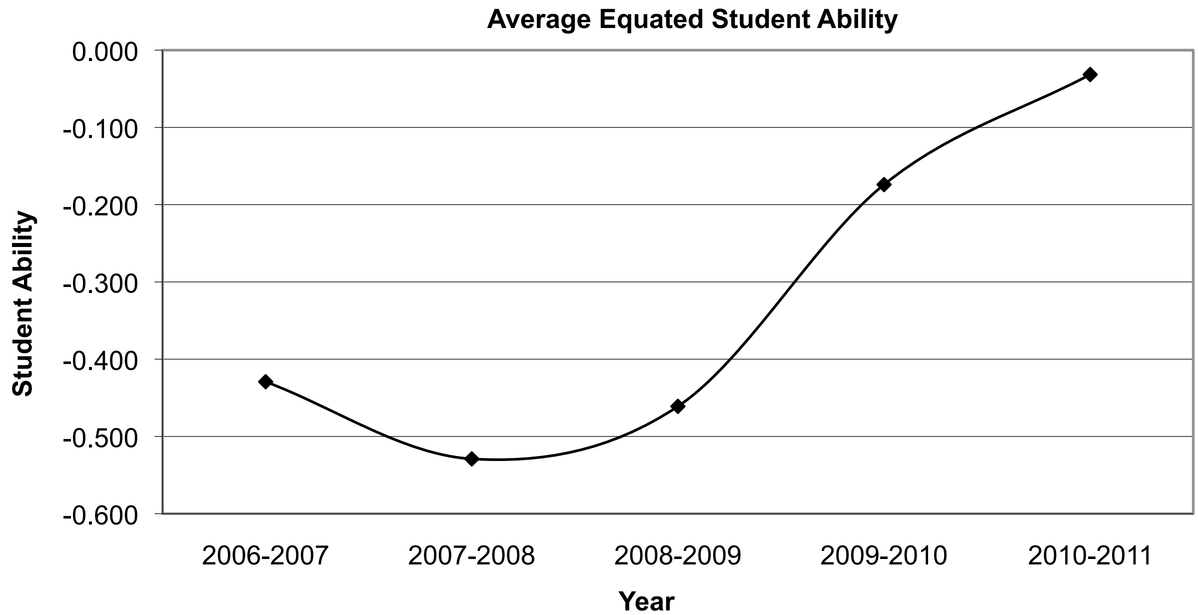


Figure 5.3: The average equated student abilities for fall 2006 through spring 2011.

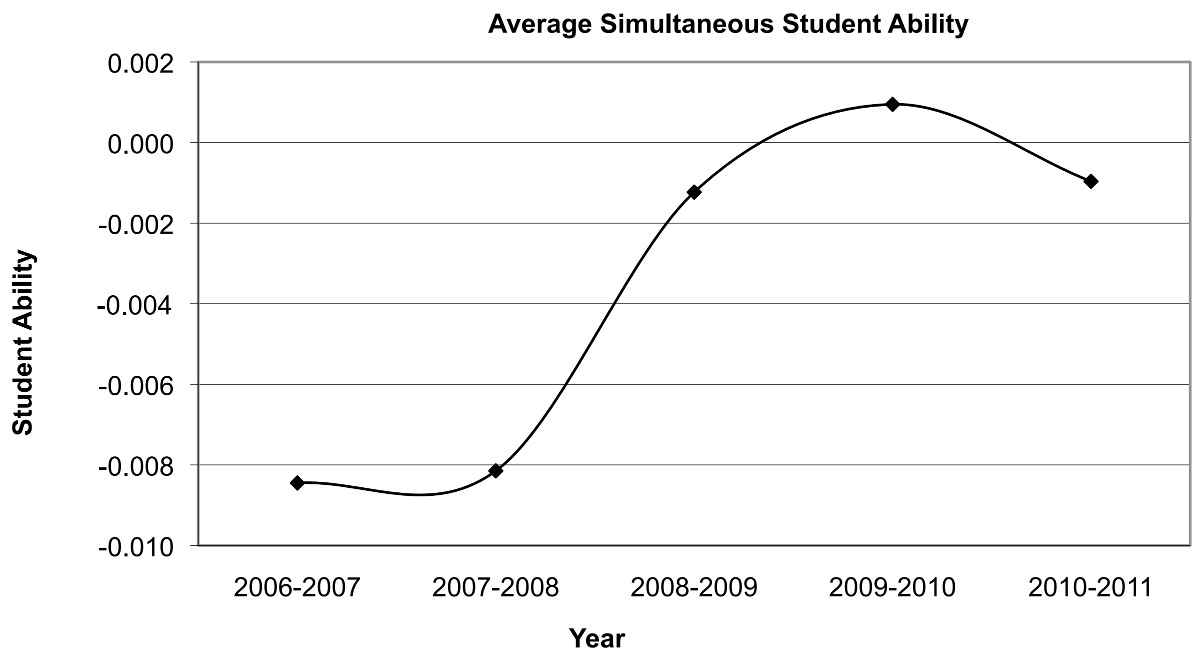


Figure 5.4: The average simultaneous student abilities for fall 2006 through spring 2011.

Discussion

The relationship between average student ability and time is certainly not linear. This relationship depends on a large number of variables such as instructor, order of course content, and the number and type of lecture innovations the instructor employs throughout the year. Though the overall trend shows an increase in student ability, the ability between the 2006-2007 and 2007-2008 academic year appears to decrease. It is difficult to pinpoint the exact cause of this decrease but it is possible that it results from a significant increase in the difficulty of the exams between those two years. This is the time interval where yearly IRT analysis of exams started to shape the exams created in subsequent years. The newly created exams were more challenging for students because they more accurately assessed student understanding of chemistry content, which is illustrated by the sudden increase in the difficulty parameters of many items during the same period of time.

Another anomaly occurs when comparing the average student ability change between the 2009-2010 and 2010-2011 academic years. In the Stocking and Lord equating analysis the average ability increases. In the simultaneous IRT analysis the average ability decreases. The exact reason for this difference remains unclear. One possible explanation revolves around the error associated with the average abilities. The average ability determined from the Stocking and Lord analysis has more uncertainty as a result of error being added when determining the transformation constants. Based solely on this information, the simultaneous IRT ability change should be more accurate. This is only a conjecture at this point; more analysis is needed to fully understand this anomaly.

A closer look at table 5.2, figure 5.3, and figure 5.4 shows that the change in average ability between any two years is not constant. Since the content of the course really hasn't changed much over the past five years, the most likely cause of this variation is the different types of lecture innovations implemented during each academic year. Table 5.3 lists the major lecture innovations for each year.

Table 5.3: Major lecture innovations implemented in general chemistry courses between fall 2006 and spring 2011.

Academic Year	Major Lecture Innovations
’06-‘07	1. Increase in the number of molecular images in lecture, homework, and tests
’07-‘08	1. Begin to align the homework questions with topics IRT analysis has shown to be difficult
’08-‘09	**1. Implement IM-Chem**
’09-‘10	**1. IM-Chem** **2. Implement remedial help sessions** **3. Implemented CLT based electronic homework questions (semester 2 only)**
’10-‘11	**1. IM-Chem (semester 1 only)** **2. Remedial help sessions** **3. Implemented CLT based electronic homework questions** 4. Problem based Integrated Instruction (PBI2)

*Boldfaced lecture innovations are discussed in previous chapters.

Conclusions

The Stocking and Lord IRT equating analysis and the simultaneous IRT analysis are both excellent ways to conduct a longitudinal study of student learning. The average ability of students in the general chemistry program at UGA has increased slightly over the past five academic years. The exact pattern and significance of this trend over time is unclear based on this limited data sample. The increase in average ability is most likely due to the implementation of numerous lecture innovations over that same period of time. Based on this analysis, it is difficult to quantify the impact each innovation had on student learning. However, the analysis does support the continued implementation of lecture innovations in an effort to continue the improvement of student learning.

Chapter 6: Conclusions

Implementation of IM-Chem in large lecture general chemistry courses has had a positive impact on student performance. IM-Chem participants had a mean course grade that was 0.14 GPA units higher than non-participants. Gains in student performance are thought to be the result of the active learning environment that IM-Chem participants experienced. Additionally, an overwhelming majority of participants stated that IM-Chem personalized the large lecture setting by providing them with an unintimidating way to ask questions and individualized answers to those questions. IM appears to be an excellent form of enhanced communication for large lecture settings. A limited number of students choose to participate in the IM-Chem intervention. Future implementations may be more successful if students were awarded course credit, or extra credit, for asking questions. Theoretically this would encourage those students who do not wish to ask questions verbally to be more active in IM-Chem. A larger participation in IM-Chem would also foster a more active learning environment within the course, which should lead to an increased impact on student performance.

The implementation of in-time remedial help sessions resulted in the development of a rigorous definition of students who are at-risk of performing poorly on subsequent tests because of their lack of understanding of one of the eleven key general chemistry concepts at UGA. This definition has tremendous instructional implications. If instructors are made aware of the number of students who are at-risk of poor performance on a particular topic, they can tailor small portions of their class instruction to help remediate the students understanding. Additionally, they could personally encourage at-risk students to attend additional help sessions if they are still confused about the topic. At-risk students who accepted an invitation to attend a help session geared towards increasing their knowledge about one of key topics consistently outperformed at-risk students who chose not to attend. An overwhelming majority of attendees found the help sessions useful and would attend a future help session if they were invited. In-time remedial help sessions are an excellent way to have an immediate positive impact on student performance. Attendance at help sessions must be increased to increase the impact on student performance. The simplest way to increase attendance is to incorporate a mandatory recitation section into the course. The recitations sections could address the eleven key topics in addition to other course content.

The pilot study of CLT based homework questions clearly demonstrates that CLT based instructional design approaches to problem solving have the potential to have a major impact on student performance in the chemistry domain. CLT based homework questions diminish the cognitive load of standard homework questions with logical three-step solutions by breaking them down into four separate questions. Question one is a fully worked out example that demonstrates the proper solution path for the learner. Questions two and three are completion problems where the learner is responsible for providing portions of the solution. In question two, the computer works out steps one and two of the solution and the learner must provide the answer to step three. In question three the computer only completes step one of the solution and the learner must complete steps two and three. Question four asks the learner to combine all of the knowledge they have acquired in questions one through four and apply it without any other assistance. There is an abundance of future research needed to quantify the breadth and depth of the impact CLT will have on the chemistry domain. Future research should focus on implementing CLT based homework questions covering a wider variety of topics. The additional topics should come from a variety of difficulty levels. Similar learning gains on topics from varying difficulty levels will help to validate the CLT implementation. Additionally, future research should actually measure the amount of load experienced by learners as they complete the newly designed homework questions. These approaches are easy to implement in most electronic homework and testing environments. The most time consuming portion of the implementation is writing effective worked out examples, completion problems, and independent problem solving exercises. This study indicates that the time invested in writing these items and other research is sure to be rewarded with gains in student knowledge retention.

The Stocking and Lord IRT equating analysis and the simultaneous IRT analysis are both excellent ways to conduct a longitudinal study of student learning. The average ability of students in the general chemistry program at UGA has increased over the past five academic years. Though the increase in average ability is not significant, it does show a trend that is heading in a positive direction. The trend indicates that the implementation of numerous lecture innovations, over that same period of time, are having a positive impact on student understanding of chemistry. Based on this analysis, it is difficult to quantify the impact each individual innovation had on student learning.

However, the analysis does support the continued implementation of lecture innovations in an effort to continue the improvement of student learning.

The overarching goal of this research was to decrease the number of D, F, and W grades issued to general chemistry students at UGA. Despite the effectiveness of each of three interventions, there was no significant decrease in the number of these grades. The lack of a significant decrease in D, F, and W grades can be attributed the small number of individuals impacted by the three interventions. To increase the impact the three interventions have on student performance, more students would have to participate in IM-Chem, a greater number of at-risk students would have to attend help sessions, and a greater number of homework questions would have to be converted to CLT based questions. An additional boost to student performance is also likely with any other interventions that target the entire general chemistry student population.

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