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Exploring Student Learning in Post-Secondary General Chemistry: Novel Tools for Measuring Linked Concepts and Study Habits

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Exploring Student Learning in Post-Secondary General Chemistry:

Novel Tools for Measuring Linked Concepts and Study Habits

by

Li Ye

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
Department of Chemistry
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ABSTRACT

This dissertation presents novel tools to help instructors measure students linking of content knowledge and the actions students perform for studying in the context of post-secondary General Chemistry.

The first tool described in this work is Creative Exercises (CEs), an open-ended assessment that has the potential to promote students making connections across the content covered in General Chemistry. Students are given a simple prompt that describes a chemistry situation, and asked to write as many statements as they can that are correct, distinct and relevant to the prompt and the course content. The written responses to CEs from both in-class exams and homework assignments are examined for evidence of linking chemistry concepts. The findings indicate that students are able to use a wide range of topics to answer CEs based on the prompts. Also, from student responses to CEs, students’ misunderstandings of chemistry models are uncovered.

To determine the prevalence of links and facilitate implementation in large classes, the second tool termed Measure of Linked Concepts (MLCs) is developed and implemented in General Chemistry. MLCs provide similar prompts as CEs and also a series of statements developed from prior student responses to CEs. Students are asked to evaluate the legitimacy of these statements. Students’ performance on MLCs is examined and the results show that the majority of students show proficiency in prior knowledge. However, a sizeable proportion of students can’t recognize the situation where a chemistry model is misused.
Student responses to the above two assessments (CEs and MLCs) provide evidence for linking chemistry concepts of students in General Chemistry, both correctly and incorrectly. They also serve as tools for showing the relevance of prior topics and subsequent topics throughout the course and communicating with students for learning chemistry as a theme instead of separated facts.

Finally, text message inquiries are used to explore student study habits in General Chemistry. Study habits are defined as the frequency and type of actions taken toward studying outside the classroom in this work. The evidence for the feasibility of using text message inquiries as a data collection tool and the validity of the collected data is presented. Students in General Chemistry are characterized as three clusters based on their study habits. The cluster of students who reported studying in addition to the required course material outperform the other two clusters of students, who knowingly do not study and who reported studying only required course materials. By tracking study habits of a common group of students, we observe the signs of adapting. In addition, study habits of students at-risk of failing the course based on incoming SAT scores are explored in this work. The results indicate both frequency and quality play a role in students’ academic performance, and quality may be more important than frequency. These results provide a path for at-risk students to improve success rates in General Chemistry.
CHAPTER I:  
INTRODUCTION

Exploring Student Learning in Chemistry

Understanding student learning and their experiences toward learning is important for instructors to make decisions for instructional practices. This dissertation describes multiple attempts to explore student learning in post-secondary General Chemistry. The starting point of this research was curiosity about the question, “what are the efforts students make to help them learn chemistry meaningfully?” From this starting point, the efforts were devoted to two specific aspects. First, developing and implementing chemistry assessments to understand what content knowledge students gained in chemistry and how much they connect gained knowledge. Second, developing novel tools to understand learning experiences of students in chemistry, more specifically, what actions students taken for studying chemistry. This work is done with a belief that such understandings are essential for educators to improve students’ learning processes and eventually increase student success rates in chemistry.

Back to the time of the 1970s, researchers found that what influenced students most was actually the assessment instead of the teaching (Snyder, 1971; Miller & Parlett, 1974). Assessments not only can help instructors to gather evidence of student learning in the courses, but also they can serve as a means to convey with students what activities and effort is required.
from them. Students may change the way they spend their time and effort because of the change of assessments (Gibbs & Simpson, 2004). Knowing the importance of assessments for student learning, we focus on the development and implementation of novel chemistry assessments in classroom. We present two assessments in this work, one named Creative Exercises (CEs) and the other named Measure of Linked Concepts (MLCs). These assessments are designed to promote students making connections for content knowledge in General Chemistry. In both of the assessments, students are given a prompt describing a simple chemistry situation, such as “10.5 grams of CO$_2$”. The prompt matches the content recently presented in the course, meanwhile, it also provides opportunities for students to make links from prior knowledge to the new contexts. In CEs, students were asked to write down statements based on the prompt. In MLCs, students are given a list of statements that were developed from prior student responses to CEs and asked to evaluate the correctness of each statement. These assessments are born out of a concern that students learn General Chemistry as separated facts. This might be harmful for students’ learning because they may rely on memorization for studying instead of assimilating newly learned knowledge into existing knowledge. CEs and MLCs reward students for making links between prior and new knowledge. The intent of these assessments is to promote students connecting knowledge, so that they can construct meanings and conceptual understanding across the content in General Chemistry. The evidence for linking chemistry concepts from student written responses to CEs are examined though a qualitative approach because of its open-ended nature (Chapter III). The development and quantitative analysis of student responses to MLCs are presented in details in Chapter IV. The use of these assessments and the evidence enable us to know what students learned and how much they connect content knowledge they learned in General Chemistry.
Research on student learning processes originated from Marton and Saljo (1976) in Sweden. In their study, the students were given a prose to read and then asked questions regarding the text they read. Student responses were characterized as surface and deep approaches to learning. Marton and Saljo describe a surface approach as “skated along the surface of the text”, in which students tried to list separate facts without comprehension. In contrast, a deep approach refers to understand the meaning of the text, students were able to interpret what the author means and see the big picture. Since then, there have been a substantial number of research articles devoted to characterizing students’ learning processes in various settings (e.g. Biggs 2001; Richards-Babb and Jackson, 2011; Li et al., 2013). However, the majority of the studies relied on single-admission surveys to characterize student learning. This method might be problematic because it relies upon retrospection of students for a long period of time, also it presumes that students’ learning is constant and cannot capture changes within student learning.

As mentioned in the beginning, our interest is to explore students’ learning experiences in chemistry, especially actions taken by students for studying chemistry. There are only a few articles that report student actions for studying chemistry (Chan, 2014; Sinapuelas & Stacy 2015; Bunce et al., 2017). Therefore, to minimize the problems aforementioned and fill in the gap in the literature, we want to explore how students study chemistry at multiple points of time and characterize the change of student learning in chemistry. For doing so, we sent a series of text message inquires to college general chemistry students over a semester: “Have you studied General Chemistry in the past 48 hours? If so, how did you study?” The feasibility of this novel tool (text messages) to collect data in chemistry is established for the first time in this work. More importantly, types and frequencies of studying for learning General Chemistry outside the
classroom, along with the patterns of adapting for studying in chemistry are characterized (Chapter V). Next, we focused on students who are considered at risk of failing chemistry based on SAT math scores. The frequency and quality of student studying in chemistry are described. Effective and ineffective study habits for at-risk students are proposed (Chapter VI). The ample data collected via text messaging technique, along with interviews characterizes the change of students’ studying across a semester and reveals the effect of the frequency and quality on student academic performance in General Chemistry.

Assessments for Linking Concepts in Chemistry

Students tend to learn chemistry as disjointed facts and as a result use rote learning or memorization. This issue has become a major concern of educators (Francisco et al., 2002). However, multiple theoretical frameworks emphasize the importance of making connections between prior knowledge and new contexts. The interactive process of making connections, in which both prior knowledge and existing knowledge need to be slightly modified to facilitate the interconnection and integration, promotes meaningful learning and longer retention (Novak, 2010; Marton & Saljo 2005; Staver 1998). To improve the ability of students to construct links in chemistry, researchers reported several classroom assessment practices in chemistry to help students make connections.

First, concept maps was one of the assessment tools used extensively to help students make links between chemistry concepts in the literature (Novak, 2010, Francisco et al., 2002). In concept maps, students are asked to draw visual representations that include different key concepts (placed in boxes) and links between them (represented by lines). Short phrases are
written on the links to indicate the relationship between key concepts. Concept maps appear to enhance students’ conceptual understanding in chemistry and provide opportunities for students to reflect upon missing or incorrect connections (Francisco et al., 2002; Joel & Kamji, 2016). However, it is also critiqued in the literature because of inconsistent grading schemes. The scoring procedures may focus on different components of the concept maps created by students. These components may involve the organization of concepts (hierarchical, associative or cyclical depend on the topics), propositions (number, accuracy, crosslinks), or examples (valid instances for the concepts). Multiple combinations of the above components are taken into account for scoring procedures. The variety of the scoring procedures may lead to discrepancies among graders of concept maps and affect the score interpretation and validity of the assessment (Ruiz-Primo and Shavelson, 1996; Lewis et al., 2011).

Next, Higher Order Cognitive Skills (HOCS) questions in chemistry were another type of assessment to help students make connections. HOCS-type questions, defined as problems that are unfamiliar to the students, require solvers to apply prior knowledge to unfamiliar contexts, and to do evaluative thinking on the basis of knowledge application, analysis and synthesis, an underlying ability described as critical thinking (e.g. give an excerpt from a research article involving Freons and ask solvers to find an appropriate substitute for Freons and provide rationale and explanation). As compared to HOCS, Lower Order Cognitive Skill (LOCS) type questions require only simple recall or knowledge application to familiar contexts (Zoller et al., 1995). Studies have reported instructional methods that promote HOCS show positive academic affect on HOCS-type of assessment for college chemistry students (Zoller, 1993; Zoller 1999; Zoller 2007). HOCS-type questions are designed to help students make connections between familiar situations to unfamiliar situations without relying too much on the content itself. It is
meant to measure students’ underlying critical thinking skills instead of measuring the construction of connected chemistry concepts.

Lastly, Rau (2015) reported using conceptual sense making and perceptual fluency-building questions in an intelligent tutoring system to help students make connections among multiple graphical representations in an introductory General Chemistry course. Conceptual sense-making questions are designed to help students relate visual features of graphical representations to corresponding conceptual aspects of chemistry content (e.g. provide pairs of graphical representations such as the Lewis structure and electrostatic potential map for the same molecule and ask about the similarities). In contrast, perceptual fluency-building questions promote efficiency in connection making on visual features among multiple graphical representations (e.g. provide many rapid classification tasks requiring contrasting cases for visual features). The study indicated that the combination of above two types of questions for connection making among multiple graphical representations is effective for students’ leaning chemistry on the metrics of multiple chemistry knowledge tests. Conceptual sense making and perceptual fluency-building questions are useful to help students make connections. However, as described by the author, the focus of them is to “help students become fast and more efficient at extracting relevant information from graphical representations”. Therefore, the intention of these questions are different than CEs and MLCs. CEs and MLCs attempt to promote students’ linking of chemistry concepts with the potential to incorporate mathematical understanding, while this system is confined to graphical representations.

In terms of the role of the assessment, HOCS-type questions emphasize critical thinking skills and questions reported by Rau emphasize connections related to graphical representations in chemistry. Instead, this work seeks to investigate the potentials for two novel assessment
techniques, Creative Exercises and Measure of Linked Concepts, to promote connections among chemistry concepts. The purpose of these assessment tools is similar to concept maps. However, they are more desirable than concept maps in different aspects. For small and medium classes, Creative Exercises would be favorable because of its consistent grading schemes. CEs provide credit for students when they construct correct and distinct relationships through writing statements that are related to the prompt, but do not require the network of relationships among statements. Therefore, the strong advantage to using CEs is a simpler grading scheme, which evaluates a series of correct and related concepts without relying on the organization of knowledge. Also, students receive no penalty for writing incorrect statements, which promotes more responses from students. To implement in large classes (more than 100), MLCs are designed and developed. MLCs have a similar prompt as CEs and a list of statements based on the prior student responses to CEs. Because of the closed-ended nature (choose “true” or “false” for the statements), MLCs benefit from automatic machine grading. The advantage of using MLCs is that it can be used to determine the prevalence of the correct and incorrect links of students. But noting that it is also possible that MLCs introduce the chance of guessing because of the true-false type of questions. The two chemistry assessments presented in this work, CEs and MLCs, provide alternative assessments for students to construct meanings between chemistry concepts and for instructors to evaluate students’ ability to make connections.

**Tools for Understanding Students’ Study Habits in Chemistry**

College students may have difficulty in making transitions from high school to college regarding how to study. Developing effective study habits in college is essential for
undergraduate students’ learning when they come to a new environment (King, 1992). For educators and researchers, learning about student experiences and factors that lead to better academic performance is important toward improving success rates in college chemistry course and retention rates in STEM fields (Chen & Solder, 2013). The association between college students’ study habits and academic performance has been reported to be small to moderate in a meta-analysis study (Crede & Kuncel, 2008). In the meta-analysis, the investigations of students’ study habits heavily rely on Likert or rating scale surveys in the research studies (N=40). However, previous research has suggested the need to incorporate qualitative approaches to measuring student study habits (Elliot, 1999).

In post-secondary chemistry, students usually spend three to five hours in the classroom each week. The majority of time students devote to study actually is outside the classroom setting. Therefore, to understand how students study when they are out of the classroom is crucial. Researchers used mainly surveys and interviews to explore student study habits in chemistry (Richards-Babb and Jackson, 2011; Li et al., 2013, Chan, 2014; Sinapuelas & Stacy 2015; Bunce et al., 2017). Richards-Babb and Jackson used a Likert scale survey to examine the gender difference in study habits at the end of a General Chemistry course. They reported that males reported study habits of being less willing to figure out mistakes and more likely to procrastinate. Chan (2014) and colleagues developed a survey consisting of both open-ended and Likert scale questions to measure study strategies for General Chemistry student in the middle of the semester. Students were asked to list the types of study strategies they used when learning in chemistry lecture and preparing for exams. In addition, students were asked to rate the frequencies of a list of provided study strategies on a 5-point Likert scale from 1 (never) to 5 (always). Students were also asked to talk about the study strategies via one-to-one interviews.
They compared the difference in learning chemistry among three student groups (high, medium and low) identified by cluster analysis based on six affective factors (test anxiety, self-efficacy, math self-concept, chemistry self-concept, emotional satisfaction and intellectual accessibility). The high student group reported understanding notes taken in lecture more frequently and relying less on others for preparing for exams than the low student group. Also, the high student group tended to evaluate more on their study strategies, noticing which are the effective strategies and planning to modify the ineffective strategies.

Bunce and colleagues (Bunce et al., 2017) surveyed students on which resources students choose for studying in General Chemistry at United States Naval Academy. A subset of students were invited to be interviewed to investigate how they used the resources they chose. They found that the three most frequently used study resources by students in their setting were past exams, student-prepared and instructor-prepared notes and personal help from others. High-achieving students who earned an A or B in the course tended to choose study resources like notes and past assessments that they can work independently of others and ask for help if necessary, while average (C) and low-achieving students (D or F) were more likely to choose study resources that provide face-to-face help from others, such as extra instruction from instructors and tutoring sessions.

In this work, we seek to use a novel tool for measuring students’ study habits in chemistry, that is, text messages. The advantage of using text messages is that it provides a way to collect both qualitative (i.e. text message responses) and quantitative data (i.e. percentages of studying, created by dichotomous coding from text message responses) for a large sample, so researchers can gather evidence of student study habits in different perspectives. More importantly, the features of text messages enable the researchers to measure students’ study
habits multiple times within a time range. This method is a much more proximal retrospective from participants, for the reason that participants are asked to reflect upon their study habits in a shorter range of time as compared to surveys or interviews that usually take place once in the middle or at the end of the semester.

Definition of Terms

Concept. In this work, the term concept adopts Taber’s description of conceptual understanding in chemistry as any knowledge that is meaningful (Taber, 2014). Meaningful knowledge requires understanding of content and relating content to each other instead of rote memorizing content as separate facts. Under this definition, algorithmic information can be considered as concept when they are applied to new contexts with understanding. For instance, students might link stoichiometry to a prompt involving masses of two gases in gas law. In such case, students are able to apply prior knowledge (stoichiometry) into a new context (gas law), the knowledge (stoichiometry) is meaningful to them and can be considered as concepts.

Linking. The term linking involves the connection or relationship between concepts. More specifically, students are able to apply prior concepts into a newly learned situation, and make connections between previous concepts and new concepts.

Study Habits. Study habits refer to the types of action taken toward studying chemistry outside the classroom and their frequencies.

At-Risk and Non-At-Risk students. Students are considered as at-risk of failing General Chemistry based on SAT math scores. A frequency distribution of student SAT math scores was divided into four quartiles. Each quartile has approximately the same number of
students. In this work, students who have the SAT math scores in the bottom (25%) quartile are identified as at-risk students. Students who have the SAT math scores in the other three quartiles (75%) are classified as non-at-risk students.

**Purposes of this Work**

The purpose of this dissertation is to use novel tools for understanding student learning of content knowledge and how students learn chemistry out of the classroom in post-secondary General Chemistry. With a more profound understanding of student learning, hopefully we can provide potential paths for improving student success rates for General Chemistry courses and help increase student retention rates in STEM fields.

The first two studies (Chapter III & IV) involve students’ linked concepts in college General Chemistry classrooms. *Study 1, Looking for links: examining student responses in creative exercises for evidence of linking chemistry concepts*, uses an open-ended assessment named Creative Exercises (CEs) to measure students’ linked concepts. The qualitative investigation into student responses to CEs showed evidence of linking chemistry content throughout the course. Misapplications of chemistry models from students were also revealed. Informed by study 1, *study 2: Developing and implementing an assessment technique to measure linked concepts*, describes another novel assessment named Measure of Linked Concepts (MLCs). The quantitative investigation into student responses to MLCs examines the evidence of the prevalence of students’ abilities to link specific concepts, both correctly and incorrectly. The ample evidence presented in these two studies enable us to propose CEs and MLCs as novel tools to measure and promote students making connections across course content in General
Chemistry and inform instructors about the links made.

The next two studies (Chapter V & VI) involve students’ study habits outside the college General Chemistry classroom. Study 3, *Learning beyond the classroom: using text messages to measure General Chemistry students’ study habits*, uses a series of text messages sent to students to measure their study habits outside the General Chemistry classroom. Analysis of 4775 text message responses collected from 301 participants showed evidence for feasibility and validity for this novel data collection tool for understanding study habits. Open coding of text messages led to 16 types of study habits employed by students and their frequencies. In order to examine the role of study habits for students’ academic performance in the context of General Chemistry, cluster analysis showed three clusters of students: students who knowing do not study, students who describe mandatory course components as studying and students who study in addition to the mandatory course components. The last cluster outperformed the other two clusters on a common exam when compared using Analysis of Variance (ANOVA). In addition, lexical analysis showed students’ study habits were changing, suggesting students adapted across the semester. Study 4, *Can they succeed? Exploring at-risk students’ study habits in college General Chemistry*, examines the relationship between students habits and academic performance for students who are considered at-risk of failing the course based on SAT math scores. The results of multiple regression analysis showed that high frequency of studying could mitigate the difference between at-risk students and non-at-risk students on final exam scores. In addition, semi-structured interviews combined with text messages of six at-risk students revealed that the quality of the studying matters for student academic performance as well. High-achieving at-risk students employed deep level approaches in learning General Chemistry. The deep level approaches involve making connections between chemistry concepts, working independently
before confirming answers with others and working collaboratively and explaining things to others. These two studies offer potential paths to improve student success in post-secondary Chemistry.

In this dissertation, Chapter II introduces the instruments, evidence for validity, and general research methods and techniques for analyses used in the studies. Chapters III and IV are published studies on assessments for linking chemistry concepts. Chapters V and VI are published studies on students’ study habits toward studying chemistry. With permissions from publishers and co-authors, each chapter has been reproduced verbatim from the published studies. Before each chapter, there is a note that provides connections between studies to help readers to make transitions smoothly. Lastly, Chapter VII provides an overall summary and discussion of the entire dissertation and future directions. As part of this work, there is a series of acronyms used in the dissertation, those are provided in a table in Appendix A for the convenience of reading.

References


CHAPTER II:

METHODOLOGY OVERVIEW

This chapter provides an overview of the methodology used in this dissertation. Instruments used in the studies, evidence for validity of these instruments, and techniques for data collection and data analysis employed in this dissertation are presented in this chapter.

**Instruments Used in the Studies**

The data in this work was collected mainly through assessments, surveys and text messages. The implementation of each instrument is presented in this section. As determined by the Institutional Review Board (IRB) in the institutions, the majority of the collected data in this work was determined exempt from informed consent because the data was collected from the normal educational setting without any study related activities. The IRB approval for this waiver can be found in Appendix B. The IRB approvals and informed consent forms for the interviews for MLCs and text messages for study habits were obtained from the university (See Appendix B).

In the beginning of each semester, prior academic and demographic information of students who enrolled in the General Chemistry course include SAT scores, gender and race was obtained from the registrar office of the university.
The revised two-factor Study Process Questionnaire (rSPQ) was implemented on the first day of the General Chemistry course as a way to record student first day attendance for instructors. The questionnaire has 20 Likert-scale items to measure two subscales of students’ study processes: surface approach and deep approach, with 10 items for each approach. For each item, the choices are ranked in an increasing level of agreement, from “never or only rarely true of me” to “always or almost always true of me”. The surface approach is characterized as relying on memorization to learning while deep approach refers to intrinsic interest and understanding. Students were instructed to consider their study processes in general for chemistry or a science course. Students used about 15-20 minutes to complete the questionnaire. Student responses were recorded on scan-trons and then were scanned into an Excel sheet. A copy of the questionnaire can be found in Appendix C.

Creative Exercises and Measure of Linked Concepts were implemented as homework assignments and parts of the midterm and final exams across the semester. Both assessments were administered using paper format. Student written responses to Creative Exercises were collected on papers. Student responses to Measure of Linked concepts were collected on scan-trons, then transformed to Excel sheets and combined with other data in SPSS.sav files. Students had four exams during the semester, three midterm exams and one final exam. The exams consisted of a CE or a MLC and multiple-choice questions. The research team in studies wrote CEs and MLCs. Multiple instructors who were teaching the General Chemistry courses wrote multiple-choice questions for the exams. Instructors were assigned certain learning objectives and wrote questions measuring the assigned learning objectives. The course coordinator then compiled the questions from different instructors for the exams. In terms of point distribution, each CE or MLC statement is graded as either one-third or half of the points of a single multiple-
choice question. All the instructors examined the length and content of the compiled exam questions before use. After the semester was completed, the researchers in this work collected student data from the normal classroom setting, including exams scores, attendance and completion of homework assignments.

A series of text messages inquiries were sent to General Chemistry students twice a week about their study habits: “Have you studied General Chemistry in the past 48 hours? If so, how did you study?” The same inquiry was sent 28 times throughout the semester. Student text response to theses inquires were collected via a management website named Mosio. All the student data were collected electronically except for the responses to Creative Exercises. Those data were combined into a single SPSS. sav file for analyses after each semester was completed.

**Validity of Instruments**

When using instruments to measure constructs, evidence for validity needed to be collected in order to have trustworthy and meaningful interpretations of test scores. To determine the validity of the instruments used in the work, we use the Messick’ framework (Messick, 1995). As summarized in Figure 1, Messick’s framework contains six aspects of validity: content, structural, generalizable, external, substantive and consequential validity. Content validity refers to the content of the instrument being relevant and representative of all the important parts of the construct domain measured. Structural validity involves the scoring structure is consistent with the theory of the construct. Generalizability refers to the degree of the correlation of the assessed task with other tasks representing the construct, or generalizability across time or raters of the task performance. External validity refers to the extent the assessment scores correlated to other measures that related to the theory of the construct. Substantive
validity involves the extent the respondents are engaged in the indented process. Consequential validity is about the consequences of score interpretation.

<table>
<thead>
<tr>
<th>Six Aspects of Validity of Assessment from Messick</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content:</strong> the content of the instrument is relevant and representative of all the important parts of the construct domain measured</td>
</tr>
<tr>
<td><strong>Structural:</strong> scoring structure is consistent with the theory of the construct</td>
</tr>
<tr>
<td><strong>Generalizability:</strong> to the degree of the correlation of the assessed task with other tasks representing the construct, or generalizability across time or raters</td>
</tr>
<tr>
<td><strong>External:</strong> the extent the assessment scores correlated to other measures that related to the theory of the construct</td>
</tr>
<tr>
<td><strong>Substantive:</strong> the extent the respondents are engaged in the indented process</td>
</tr>
<tr>
<td><strong>Consequential:</strong> evaluation of the consequences of score interpretation</td>
</tr>
</tbody>
</table>

**Figure 1.** Messick’s Framework for Validity of Assessment

For the revised two-factor Study Process Questionnaire, the evidence for validity has been reported in the literature (Biggs, 2001). We examined the Cronbach’s $\alpha$, a metric indicating the internal structural of instrument. The Cronbach’s $\alpha$ values for the two factors (Surface Approach and Deep Approach) of the rSPQ are 0.776 and 0.826, these are in line with the values reported in the literature (Biggs, 2001).

The evidence for validity of Creative Exercises was examined and reported by Lewis (2011), including content, structural, generalizability and external validity. Content validity was examined through matched content coverage between CEs prompts and topics in the course. For the structural validity, the scoring criteria give credit when students write correct and distinct statements that are related to the prompt and material presented across the course. These criteria are in line with the intention of CEs, to promote students making connections across the content in the course. The correlations among raters for both in-class CEs and homework CEs showed the evidence for generalizability. External validity was examined by correlations with a
traditional chemistry assessment. More details about the evidence for validity for CEs can be found from the published paper (Lewis, 2011).

For Measure of Linked Concepts, the content validity was established by having multiple instructors who were teaching the General Chemistry course examined the content of the assessments before implementing them as homework assignments or exams. Evidence for structural validity includes correlation patterns among partial scores and total scores for MLCs. The correlation between scores on each statement in MLCs and the overall MLCs can be found in Chapter IV, tables 6 to 7 in Chapter VI. The average correlation of scores on single statement and overall scores on MLCs was 0.398 and the correlations are in the range of 0.157 to 0.600. This indicates some items in the MLCs with low correlations that need to be revisited and revised. The evidence for generalizable validity for MLCs can be addressed via scores on MLCs across tasks. Evidence was established by examining the correlations between MLCs and each exam scores of students (see table 1 below). Because MLCs were part of the exams, the correlations between MLCs and others questions (multiple-choice questions) in each exam were calculated (see table 1 below). As a result, there is an expected average correlation of 0.462 between MLCs and multiple-choice questions on relevant exams, which demonstrated moderate agreement. This correlation is consistent with the value reported in the literature, because the value of 0.50 is reported by multiple articles as typical correlations between different alternative types of assessments and conventional assessments in chemistry (Liu and Hinchey, 1996. Rice et al., 1998, Lewis, 2011). Much higher correlations may indicate a redundancy between the two measures of MLCs and multiple-choice questions, while much lower correlation may bring to question whether MLC scores reflect students’ chemistry knowledge.
Table 1. Correlations between MLCs and relevant exam

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Relevant exam</th>
<th>Multiple-choice questions on relevant exam</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLC 1</td>
<td>0.724</td>
<td>0.556</td>
<td>1609</td>
</tr>
<tr>
<td>MLC 2</td>
<td>0.674</td>
<td>0.490</td>
<td>1550</td>
</tr>
<tr>
<td>MLC 3</td>
<td>0.602</td>
<td>0.302</td>
<td>1460</td>
</tr>
<tr>
<td>MLC 4</td>
<td>0.641</td>
<td>0.499</td>
<td>1366</td>
</tr>
<tr>
<td>Average</td>
<td>0.660</td>
<td>0.462</td>
<td>1496</td>
</tr>
</tbody>
</table>

Substantive validity was acquired by examining student response process to MLCs. Students were asked to “think aloud” the reasoning behind their choices for statements. Originally, MLCs were developed to have students judge the correctness of the statements by selecting “True” or “False”. Based on student interviews, some extent of guessing (Not sure) was found (see Appendix D). To reduce the chance of guessing, the research team discussed and added an “Unsure” choice to the assessment, the choices were then modified to “True” or “False” or “Unsure” in MLCs. Students choosing “Unsure” would receive partial credit (one third of the points) on the question.

For text message as a tool to measure student study habits in chemistry, content validity and generalizable validity was provided (Chapter V). With regard to content validity, the text message responses were coded by two researchers and resulted in sixteen types of study habits. The frequency of each type of study habits was also calculated (See Table 13 in Chapter V). There were six types of study habits employed by students more often than 5%: did not study (42.2%), reviewed notes or PowerPoint (18.8%), reviewed the textbook (16.4%), online homework (14.2%), practiced problems (6.8%), and previous exams or study guides (5.7%). In addition, text message responses were coded dichotomously as students report studying or not studying. Using the dichotomous codes of those participants who replied to at least half of the 28
inquires (N=188), the percent of students reporting studying peaks at the exam date. This phenomenon matches the instructional expectations. In terms of generalizable validity, measuring by t-test, chi-square test and effect size, self-selected participants in the study are comparable to student populations at the setting with only small departures according to the variables of SAT math scores, SAT verbal scores, percentages of female, percentages of under-represented minority, and deep approach and surface approach measured by rSPQ (Chapter V Table 12). Because we selected a subset of participants to do the analyses, students who replied to at least half of the text message inquires, we investigated the self-selection bias in this study as well. First, we examined the correlations between frequencies of text message responses and a series of variables (SAT math, SAT verbal, surface approach, deep approach, percentage of female, percentage of minority) for all the participants, those correlations were found to be weak. Then, we examined the correlations for the selected sample using same variables, and found all the correlations were weak as well (r < 0.17). Second, we compared the final exam scores, course GPA, percentages of female, percentages of minority, and SAT math and verbal scores for the selected sample and non-selected sample, and the effect sizes were calculated and listed in Table 2. The effect sizes were considered to be small to moderate (Cohen, 2005). Therefore, there is minimal evidence indicated that the sample is biased.

**Table 2. Comparison between selected sample and non-selected sample**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Selected sample Mean (SD)</th>
<th>Non-selected sample Mean (SD)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final exam</td>
<td>47.2 (14.4)</td>
<td>48.8 (16.1)</td>
<td>d* = 0.10</td>
</tr>
<tr>
<td>Course GPA</td>
<td>2.52 (0.87)</td>
<td>2.47 (0.96)</td>
<td>d = 0.05</td>
</tr>
<tr>
<td>% of female</td>
<td>66%</td>
<td>60%</td>
<td>w* = 0.06</td>
</tr>
<tr>
<td>% of minority</td>
<td>46%</td>
<td>40%</td>
<td>w = 0.07</td>
</tr>
<tr>
<td>SAT math</td>
<td>562 (63)</td>
<td>548 (67)</td>
<td>d = 0.22</td>
</tr>
<tr>
<td>SAT verbal</td>
<td>560 (73)</td>
<td>544 (72)</td>
<td>d = 0.22</td>
</tr>
</tbody>
</table>

* d = 0.2 (small), 0.5 (medium) and 0.8 (large); * w = 0.2 (small), 0.5 (medium) and 0.8 (large)
Mixed-methods Research Design

Mixed-methods research design involves both quantitative and qualitative approaches in design, data collection, and data analysis. Tashakkori and Creswell (2007) defined mixed methods as “research in which the investigator collects and analyzes data, integrates the findings, and draws inferences using both qualitative and quantitative approaches and methods in a single study or program of inquiry”. Studies can be considered as “mixed” when they involve qualitative or quantitative approaches in one or more of the following aspects: research questions, the rationale for developing the research questions, sampling procedures (e.g., probability and purposive), data collection (e.g., interviews and surveys), types of data collected (numerical and textual), data analysis (statistical and thematic), and the conclusion (e.g., objective and subjective) (Tashakkori & Teddlie; 2003, Teddile & Yu, 2006; Tashakkori and Creswell, 2007). Quantitative approach is robust in measuring how prevalent a phenomenon is, while qualitative approach elucidates a deep understanding about what the phenomenon means. Combing quantitative and qualitative approaches, researchers can offer unique insights in the interested topics.

In the study of using text messages to explore students’ study habits, quantitative and qualitative approaches are integrated to answer research questions. Qualitative data includes text message responses and transcriptions of semi-structure interviews. Quantitative data contains dichotomization of text message responses, SAT scores, student exam scores, course GPAs, student responses to Likert scale questionnaire (rSPQ) and other measures regarding student effort in the classroom such as percentages of completion of homework assignments and percentages of attendance for classes. Various techniques and software were utilized to analyze the above qualitative and quantitative data. The analysis methods are described in next section.
Data Analysis

Analysis for Qualitative Data

Open coding is a technique used to analyze textual data sources, including labeling concepts and defining and developing categories according to their properties (Corbin & Strauss, 2008). In this work, text message responses and interview transcriptions were analyzed using an open-coding method. For the text message responses to inquiries asking students’ study habits, the coding results in sixteen types of study habits employed by students in General Chemistry and their frequencies of using these types of study habits (see Table 13 in Chapter V). For the six at-risk students’ interview transcriptions, open coding led to a code list including 137 codes. The codes were divided into six categories based on the nature of the codes. These categories are study approaches, metacognition, affective factors, impression on chemistry, study environment, and other factors that may affect performance. The last three categories were not reported in this dissertation due to the limited number of codes in these categories. The complete code list can be found in Appendix E. Except for text message responses, open coding was also utilized for evidence of linking chemistry concepts by examining student responses to Creative Exercises. Statements written by students to Creative Exercises were categorized as correct, incorrect and irrelevant codes. Then these codes were organized based on major topics according to common chemistry textbooks. The resulting code list contains frequency of codes and classifications by topics and correctness, which is included in Appendix F. The codes for student responses to Creative Exercises and text messages, researchers’ notes on papers were used to help the coding process. The codes for the interview data were organized using Nvivo 11.1.1 software. The
advantage of using software for the author in this work is it organizes the codes in a way that is easier to read quotations under the same codes or categories from multiple interviewees.

In addition to open coding, lexical analysis was also used to analyze student text message responses using SPSS Text Analytics (IBM, 2011). The software extracted common categories using linguistic-based text analysis. The phrases using synonyms (e.g. reviewing textbooks and reading textbooks) are combined into one category. Lexical analysis also provides insights into the sizes of categorizes and the extent of overlap between categories in terms of web diagrams. A common group of participants (N=113) who replied to the text message inquires sent out closest to the four exam dates were selected and their responses were analyzed using lexical analysis. The lexical analysis resulted in eighteen categories representing types of study approaches of students. The findings indicated the interconnections among types of study approaches of students and signs of change, which may be evidence of students adapting across the semester according to the four web diagrams (Chapter V Figures 9 to 12).

**Analysis for Quantitative Data**

With regard to quantitative data, inferential statistic analyses consisting of t-test, chi-square tests, analysis of variance (AVOVA) and multivariate analysis of variance (MANOVA) were performed. These statistical analysis methods rely on the same assumptions, including independence of observations, normality (the distribution of the residuals are normal), and homogeneity of variances (the variance of data in groups should be the same) (Cody & Smith, 2006). We used the same alpha level (0.05) for the tests, the probability of rejecting the null hypothesis when it is true. The common purpose of using the above tests is to compare the mean difference among groups and examine whether these differences are statistically significant.
They were chosen in different situations because of their unique features. T-tests and chi-square tests were used to test the equivalence for participants and non-participants in the work of student study habits (Chapter V & VI). T-test is commonly used for comparing between two samples. The two groups were compared on the metric of SAT math scores, SAT verbal scores and deep approach and surface approach measured by Study Process Questionnaire using two one-sided t-tests for establishing equivalence. The demographic characteristics include gender and minority status were compared using chi-square tests because the data was percentage. Additionally, cluster analysis was used to combine students who with similar study habits in clusters. Analysis of variance (ANOVA) was utilized to test the difference among three clusters on final exam scores. ANOVA is usually used to analyze the difference among three or more groups for a single dependent dependent variable. MANOVA is similar to ANOVA, but it extends to multiple variables simultaneously. Using MANOVA can increase statistical power, which can detect smaller differences that multiple times of ANOVA can’t detect when the dependent variables are correlated. MANOVA was used to compare the differences between at-risk and non-at-risk students on a series of variables. In addition, multiple regression analysis was employed to predict student academic performance using SAT math scores, percentages of studying, and the interaction between the two variables. For all the above quantitative analysis, SPSS Statistics software was used except for MANOVA was conducted using SAS software.

References


CHAPTER III:
LOOKING FOR LINKS: EXAMINING STUDENT RESPONSES IN CREATIVE EXERCISES FOR EVIDENCE OF LINKING CHEMISTRY CONCEPT

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Supplementary information for this Chapter can be found in Appendix F.

Introduction

A key decision a chemistry instructor makes is in deciding how to assess student knowledge. The assessments used play the primary role in providing feedback to students and guiding future instructional decisions. Further, the assessments used convey to students which information and level of understanding the instructor deems important and as a result serves to direct students’ academic efforts. Despite the importance of classroom assessment practices, they have received relatively little attention in the research literature, compared to, for instance, the sizable literature on developing, implementing, and evaluating alternative practices for introducing content to students (Holme *et al.*, 2010).

This study seeks to investigate the potential for a novel assessment technique, termed Creative Exercises, to promote students’ linking of concepts within General Chemistry. These
efforts are born out of a concern that students memorize information, without assimilation into students’ existing frameworks, and therefore do not develop or retain a conceptual understanding (Nyachwaya et al., 2014). Additionally, there is a concern that students view the General Chemistry curriculum as a disjointed set of topics, a perception that would further hamper efforts to link concepts (Francisco et al., 2002).

**Creative Exercises**

Creative Exercises (CEs) are an open-ended assessment practice that does not have a single or small set of possible correct answers. In essence, a CE provides students a prompt that describes an idea relevant to the course, such as “a million molecules of \( \text{SO}_2 \)” and students are asked to describe as many statements as they can that are distinct, correct, and relevant to the prompt. Generally speaking, the prompt is designed to match content that is currently being assessed in the course. Credit is awarded for each statement that a student can list which satisfies the criteria of distinct, correct, and relevant. Students are informed in each CE how many statements are needed for full credit to provide a cap on the amount of credit students can receive on an individual assignment. To promote creativity, students are also informed there is no penalty for incorrect statements. To score a CE, an instructor brainstorms a list of likely answers prior to grading. Usually the maximum statements required by students for full credit is determined by taking one-third to one-half of the number of statements the instructor brainstorms. In grading CEs if an unanticipated statement arises, the instructor makes a decision using the distinct, correct, and relevant criteria. If the statement satisfies the criteria, it is added to the list of potential answers to ensure consistent grading with subsequent students. Examples
of CEs that have been used in General Chemistry along with detailed information on the scoring process can be found in Lewis, et al. (2010). Evidence for the validity of CEs as a student assessment practice in a General Chemistry classroom has been collected through examining the content coverage, scoring structure, inter-rater reliability, and correlations with a traditional chemistry assessment (Lewis et al., 2011). As a measure of chemistry knowledge stronger evidence for validity was available when CEs were used in-class as opposed to given as homework. Homework CEs still have the potential to offer students’ preparation with the assessment technique and can serve as formative feedback to the students.

One strong advantage to using CEs is that they incentivize students to link prior concepts in the course with concepts currently presented. Students who can draw on past content and link it to the prompt given will have more chance to succeed on a CE. However, there is also the possibility that students can find sufficient information on a single topic that directly pertains to the prompt and therefore succeed without linking content. The over-arching goal of this study is to explore student responses to CEs for the extent and nature of their efforts to link prior concepts.

**Theoretical Frameworks**

The theory base that guides this work is Ausubel’s Assumptive Learning Theory (Novak, 2010). In this theory, learning is placed on a continuum between meaningful and rote. Rote learning is where the learner makes no effort to incorporate new information into existing knowledge structures. Rote learning is often characterized as efforts in direct memorization. Examples of tasks that use rote learning are memory tests where individuals are asked to
remember a sequence of unassociated letters. A chemistry example would be to ask a first year chemistry student to recall the color of a particular metal when it is put in a flame test. As the information that is being recalled has no meaningful association with existing content knowledge, the information must be learned through rote learning.

Meaningful learning, in contrast, is characterized by incorporating new information into an existing knowledge structure. The process for meaningful learning is interactive. Both the new information and the existing knowledge structure become slightly modified to facilitate the interconnection between the two. A chemistry example would be for a first-year student learning the solubility of ionic compounds and covalent compounds, to recognize that the different solubility processes can be added to their prior understanding of the differences in physical properties between ionic and covalent compounds. Emphasizing meaningful learning is essential in students’ conceptualizing chemistry as a framework of linked concepts that offer explanatory value instead of a discrete set of factors to be memorized (Taber 2014).

Rote and meaningful learning are differentiated by how they play a role in concept retention (Novak, 2010). Concepts that are learned by rote learning typically feature very limited retention and are simply forgotten. There is the potential for overlearning, where material is restudied well past recall has been achieved, which can lead to longer retention. Remembering one’s own phone number would be an example of such overlearning. In contrast, meaningful learning will generally lead to a longer retention of new concepts. Owing to the interactive nature of meaningful learning, the new concept is modified to incorporate with the existing knowledge structure. Over time the learner will be able to retrieve the general attributes of the new concept as they pertain to the now modified knowledge structure, however the learner will not be able to recall exact details of how a concept was presented. One key difference between
rote and meaningful learning, then, is the ability to recall information verbatim. Rote learning would be ideal for the direct recall of verbatim information; meaningful learning would struggle with this owing to the modification of the new information. Meaningful learning would be ideal for longer-term retention of the use of the concept.

The concept of rote versus meaningful learning have similarities with other established educational theories. Novak (2010) points to the similarities between this framework and Marton and Saljo’s (1976) work on surface versus deep learning. In surface learning, students are described as focusing on the text as written and this learning can be characterized by direct recall of the text. Students using deep learning focus on the intentional content of the text and can be characterized by comprehension of the text. Later work found that deep learning could be described as holistic, where students related content to a larger context (Marton and Saljo, 2005). In contrast, surface learning was atomistic, focusing on the sequence of the text and details within the text.

The description of meaningful learning as an interactive process is also compatible with constructivism’s account of accommodation (Tsaparlis 2014). As Staver (1998) writes, in constructivism the learner evaluates new concepts based on the concept’s ability to fit into the learner’s existing conceptual network. When a concept leads to an unexpected result, termed a perturbation, it is a sign that the concept does not fit within the existing conceptual network. Modifying the existing conceptual network to accept the new concept eliminates the perturbation, a process termed accommodation. Thus, similar to Assumptive Learning’s meaningful learning, the existing conceptual scheme is modified when learning the new concept. More broadly, the importance and characterization of linking new concepts to existing concepts is a central theme in at least three widely used educational theories.
Returning to Assumptive Learning Theory, there are actions teachers can take to emphasize meaningful learning. One of the most important actions is the nature of how students are tested. Testing the recall of definitions or principles in verbatim emphasizes rote learning. However, testing the linking of new information with existing information, would emphasize meaningful learning. Novak (2010) prescribes concept maps as an assessment technique to measure students’ linking of concepts, and therefore encourage meaningful learning. Concept maps as an assessment technique require students to create a map that link separate concepts within a course with a brief phrase termed a proposition. Students may be provided with a list of concepts, asked to generate their own concepts or a combination of both (Stoddart 2000). Multiple scoring schemes have also been developed for concept maps, each of which necessarily makes an assumption regarding the nature of a correct mapping of concepts, which is problematic as multiple organization schemes may lead to successful understanding (Lewis et al., 2011, Ruiz-Primo and Shavelson, 1996). CEs are proposed as an alternative assessment technique to concept maps that still intends to promote students’ linking of concepts. The use of CEs as a classroom assessment may be preferable to concept maps as CEs have a simpler scoring method that does not require an assumption regarding appropriate organization schemes. The overarching hypothesis tested here, then, is that CEs can serve as an alternative assessment technique that can inform instruction by compelling students to link concepts throughout chemistry.
Research Questions

To explore this hypothesis the following research questions guided this study:

1. How frequently do students link chemistry concepts when responding to CEs?

2. How do student responses to CEs inform the nature of linked concepts throughout a General Chemistry course?

Methods

CEs were incorporated into the homework and in-class exam assignments at two large, primarily undergraduate institutions in the southeast United States. CEs from three classes were selected to be coded. The classes were chosen to ensure variety in terms of institution and sufficient class size (N > 30) to provide ample variety of student responses for analysis. Within each class, CEs were chosen to have variety in terms of whether the CE was given as homework or in-class as part of an exam and the extent they provided mathematical information. The inclusion of a homework CE, despite the weaker evidence for validity, was chosen to determine if this method of using the assessment could also provide information to the instructor regarding students’ efforts to link concepts. At one institution, the content covered up to the CEs examined were in sequence: conversions, atomic structure, compounds, stoichiometry, solution chemistry, gas laws, and thermodynamics. For this institution, two CEs were examined, one that followed gas laws and one that followed thermodynamics. At the other institution, the content sequence up to the CE was: conversions, atomic structure, compounds, stoichiometry, electronic structure of atoms, periodic trends, models of chemical bonding, Lewis structures, and molecular shapes. The CE examined followed the molecular shapes topic. All of the CEs analyzed came after
students experienced at least one homework CE and one in-class CE. IRB approval was obtained at both institutions to conduct this study.

This research employs a qualitative approach. Two researchers independently coded the student responses from each CE. The initial code list was the rubric of correct answers that instructors used to grade the CEs. The code list was expanded as unexpected correct answers or incorrect answers appeared, in congruence with an open coding scheme. Once complete, the researchers compared codes and discussed any discrepancies until they reached a consensus. The resulting consensus codes were next characterized as correct, incorrect or irrelevant statements. Irrelevant statements were those statements that were correct but were statements that restated the prompt (e.g. the reaction given is balanced), restated information from the periodic table or well known constants, used a negative statement to exclude general categories (e.g. this is not a redox reaction), or were not relevant to the content in the course (e.g. FeCl₂ is a yellow solution, where qualitative chemistry was not presented). The codes were then organized based on major chemistry topic as suggested by the chapter titles in common chemistry textbooks (Silberberg, 2008, Brown et al., 2008). The complete code list, including frequency of responses and classifications by correctness and topic, are included as in Appendix F.

Results

Gas Laws CE

The Gas Law CE (Figure 2) was given in-class and described an acid-metal reaction in solution to evolve a gas with the volume and molarity of the acid and the reaction pressure and
temperature given. Students needed seven statements with this CE to receive full credit and could get extra credit for two additional statements.

| Reacting 1.45 L of 0.41 M of HBr with excess Calcium Ca (s) + 2 HBr (aq) → H₂(g) + CaBr₂(aq) This reaction occurs at 1.61 atm and 45 degrees Celsius |

**Figure 2.** CE Prompt used with Gas Laws

There were 67 students who completed the Gas Law CE and their responses are categorized by topic and correctness in Table 3. Statements categorized as irrelevant were not considered in the analysis. In Table 3, the number of students who attempted to incorporate each chemistry topic in their response is indicated. These responses are also delineated in terms of how many made correct statements and incorrect statements. Note, the number correct and number incorrect are not mutually exclusive as a student could make both a correct description of a topic and incorrect description of the same topic within their responses. For example, under the topic of Compound in Table 3, ten students provided information related to compounds. One student described CaBr₂ as a salt and HBr as a salt where the first statement was categorized as correct and the second as incorrect, and therefore this student was counted under each column. Tables 4 and 5 can be interpreted in a similar fashion.

**Table 3.** Topics Used with Gas Laws CE

<table>
<thead>
<tr>
<th>Topic</th>
<th>Students attempting</th>
<th>Number correct (%)</th>
<th>Number incorrect (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversions</td>
<td>43</td>
<td>42 (98%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Compound</td>
<td>10</td>
<td>9 (90%)</td>
<td>3 (30%)</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>62</td>
<td>57 (92%)</td>
<td>36 (58%)</td>
</tr>
<tr>
<td>Solution Chemistry</td>
<td>48</td>
<td>41 (85%)</td>
<td>34 (71%)</td>
</tr>
<tr>
<td>Gas laws</td>
<td>40</td>
<td>13 (33%)</td>
<td>35 (88%)</td>
</tr>
</tbody>
</table>
The most common response among the students was the use of stoichiometry calculations with this problem. Of the 67 students, 51 correctly converted the molarity and volume of HBr into moles. Calculations based on this figure were less common as only 23 students solved the moles of other components in the solution and 21 students found the mass of the same. Other stoichiometry calculations involved 25 students determining the molecular mass of a compound in the reaction and one student determining the percent composition of a compound. Surprisingly, 22 students used the ideal gas law and the values given in the prompt, mistakenly attributing the volume of solution as the volume of a gas, to solve for moles.

Solution chemistry had considerable variety among student responses. Numerous students identified factors relevant to a reduction-oxidation reaction, where 14 student responses assigned oxidation numbers to the chemicals, nine students identified Ca as being oxidized or HBr as being reduced and six students identified the respective oxidizing and reducing agents. Five students identified the reaction as either single replacement or reduction-oxidation. Eleven students described the solubility of either CaBr₂ or HBr and seven students identified HBr as an acid. Twelve students used terms to identify the situation as a limiting reagent or excess of calcium. In terms of common errors, 11 students incorrectly attempted to identify an ionic equation to represent the reaction and seven students described calcium as a precipitate despite its placement as a reactant.

This prompt was timed to match the presentation of gas law content and is evidenced by the 40 students who attempted to use gas laws. Of those 40, only 10 students successfully determined the volume of gas created. One student expanded on this by describing the density of the hydrogen gas created. Fourteen other students attempted to solve for density but did so incorrectly. The other common mistake was the aforementioned use of the volume of the
solution into the Ideal Gas Law. Four students solved for the volume of gas but used the moles of the reactant, without taking into account the mole ratio to the hydrogen gas produced.

In terms of the remaining topics in Table 3, the majority of students (42) were able to use the common conversion from Celsius to Kelvin. Nine students used content related to the introduction of compound, by either describing CaBr$_2$ as an ionic compound or salt, applying the nomenclature to name a compound in the reaction correctly or identifying cations and anions in the reaction.

**Thermodynamics CE**

The CE presented in Figure 3, described a dissociation reaction in water with information on the amount of reactant and water, initial water temperature and heats of formation. This CE models a calorimetry type problem and was given as a homework assignment following the introduction of Thermodynamics. Students received credit for up to seven distinct statements with this CE.

<table>
<thead>
<tr>
<th>In the reaction, below 23.0 g of FeCl$_2$ undergoes the reaction in 5.15 L of water initially at 25.0 Celsius (assume 1.0 g / mL).</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeCl$_2$(s) $\rightarrow$ Fe$^{2+}$(aq) + 2 Cl$^-$ (aq)</td>
</tr>
<tr>
<td>$\Delta H_{f}$(FeCl$_2$) = $-341.8$ kJ/mol</td>
</tr>
<tr>
<td>$\Delta H_{f}$(Fe$^{2+}$) = $-87.9$ kJ/mol</td>
</tr>
<tr>
<td>$\Delta H_{f}$(Cl$^-$) = $-167.46$ kJ/mol</td>
</tr>
</tbody>
</table>

**Figure 3.** CE Prompt used with Thermodynamics

There were 31 students who completed the Thermodynamics CE and their results are summarized in Table 4.
<table>
<thead>
<tr>
<th>Topic</th>
<th>Students attempting</th>
<th>Number correct (%)</th>
<th>Number incorrect (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversions</td>
<td>13</td>
<td>11 (85%)</td>
<td>2 (15%)</td>
</tr>
<tr>
<td>Atomic Structure</td>
<td>1</td>
<td>1 (100%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Compound</td>
<td>6</td>
<td>6 (100%)</td>
<td>1 (17%)</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>21</td>
<td>19 (90%)</td>
<td>6 (29%)</td>
</tr>
<tr>
<td>Solution Chemistry</td>
<td>13</td>
<td>11 (85%)</td>
<td>6 (46%)</td>
</tr>
<tr>
<td>Gas laws</td>
<td>5</td>
<td>0 (0%)</td>
<td>5 (100%)</td>
</tr>
<tr>
<td>Thermodynamics</td>
<td>25</td>
<td>16 (64%)</td>
<td>19 (76%)</td>
</tr>
</tbody>
</table>

The most common response to this CE targeted the intended topic of Thermodynamics. Nine students correctly calculated the enthalpy of the reaction. Ten students identified the reaction as exothermic, surprisingly only four of those students also identified the correct enthalpy of reaction. Two of the students that identified an exothermic reaction incorrectly solved the enthalpy of reaction yet still arrived at a negative number. One other student arrived at a positive number for enthalpy but described the reaction as exothermic. This highlights the potential for some links to appear meaningful even with an incorrect student understanding and represents a limitation of CEs (that is similar to traditional multiple choice assessments). To minimize this impact, CEs require students demonstrate multiple links for successful completion, with the scoring structure set up to provide more credit for demonstrating a correct understanding (e.g. a correct value for enthalpy and exothermic determination results in two correct statements).

Only two students successfully determined the energy released by the reaction, while seven other students incorrectly attempted to do so. Overall, eight students miscalculated the enthalpy of reaction, with four students subtracting reactants from products, two students missing the coefficient from chlorine and two students combining both mistakes. Three students
attempted to solve for the energy associated with each chemical in the reaction by multiplying the number of moles by the heat of formation for each chemical. One other student compared the heats of formation and concluded that FeCl$_2$ releases the most energy and Fe$^{2+}$ releases the least.

In the stoichiometry topic, 13 students successfully converted the mass of the reactant into moles, while seven other students only described the molar mass of the compound. Of the 13, seven went on to determine the moles of other components. Interestingly, three students described the percent composition by mass of the FeCl$_2$ compound. In terms of incorrect responses, two students incorrectly solved for the moles of the reactant. Two other students took the moles of FeCl$_2$ and used Avogadro’s number with one description of the resulting value as “atoms of FeCl$_2$” and another description as “molecules FeCl$_2$”.

In solution chemistry, nine students recognized the reaction as a dissolution or dissociation reaction. Eight students described FeCl$_2$ as soluble. Two students correctly determined the molarity of FeCl$_2$ in the situation while three other students incorrectly calculated molarity. Similar to the previous CE, two students described the reactant as a precipitate and one other student described FeCl$_2$ as insoluble. Also similar to the above was the misapplication of gas law relationships to a reaction in solution. Four students attempted to use the volume of the solution in the Ideal Gas Law to solve for the resulting pressure. One of the students also employed Avogadro’s Law and the moles before and after to determine the new volume of the solution. A separate student described: “When (sic) the information that the water is 1.0 g/mL and at 25$^0$ C, we know that it is in (STP) standard temperature and pressure. And so the pressure = 1 atm.”
In the remaining topics in Table 4, eleven students showed conversions of the temperature or volume of water into other units. One student correctly described the number of protons and electrons present in Fe and Cl separately. Four students correctly identified characteristics of a compound such as naming FeCl$_2$ as Iron(II) chloride, identifying the compound as ionic or identifying the cation and anion present. One student described the charge incorrectly, labeling chlorine as a -3 charge.

**Molecular Shapes CE**

The Molecular Shapes CE, presented in Figure 4 describes a single molecule with one central atom and the electronegativity values for each atom. This CE was given in-class as part of an exam on molecular geometries and bonding theories. Students received credit for up to five distinct statements with this CE.

\[
\begin{align*}
\text{Electronegativity values: } & C = 2.5, H = 2.1 \text{ and } O = 3.5 \\
\text{COH$_2$ where } & C \text{ is the central atom}
\end{align*}
\]

**Figure 4.** CE Prompt used with Molecular Shapes

There were 31 students who completed the Molecular Shapes CE and their results are summarized in Table 5.
Table 5. Topics used with Molecular Shapes CE

<table>
<thead>
<tr>
<th>Topic</th>
<th>Students attempting</th>
<th>Number correct (%)</th>
<th>Number incorrect (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic Structure</td>
<td>1</td>
<td>1 (100%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Compound</td>
<td>1</td>
<td>0 (0%)</td>
<td>1 (100%)</td>
</tr>
<tr>
<td>Stoichiometry</td>
<td>8</td>
<td>7 (88%)</td>
<td>1 (13%)</td>
</tr>
<tr>
<td>Periodic Trends/ Electron Configuration</td>
<td>3</td>
<td>3 (100%)</td>
<td>3 (100%)</td>
</tr>
<tr>
<td>Lewis Structure</td>
<td>31</td>
<td>27 (87%)</td>
<td>17 (55%)</td>
</tr>
<tr>
<td>Geometry/Shape</td>
<td>28</td>
<td>28 (100%)</td>
<td>9 (32%)</td>
</tr>
<tr>
<td>Valence Bond Theory</td>
<td>10</td>
<td>9 (90%)</td>
<td>5 (50%)</td>
</tr>
</tbody>
</table>

The student responses to the CE on Molecular Shapes featured less variety of topics than the other CEs. Every student except one attempted to draw a Lewis structure. The other student provided a written description of the carbon atom in the Lewis structure. There were 21 students who were able to correctly draw the Lewis structure and nine students who drew an incorrect Lewis structure. Students indicated a variety of descriptions regarding the structure, such as the molecule satisfies the octet rule (4 students), carbon obeys the octet rule (3 students), carbon has no lone pairs (3 students) or there are 12 valence electrons (3 students). There were also descriptions of properties that expand on the Lewis structure. Two students determined the electronegativity differences in the bonds, one student followed by stating “polar bonds between each element” and the other student assigned polarity incorrectly, labeling the carbon to oxygen bond nonpolar and the carbon to hydrogen bond polar.

Among the nine incorrect Lewis structures, five students did not record the total number of valence electrons. Of the four with the total number of valence electrons, two students had the correct structure except each placed both a single bond and three lone pairs of electrons on oxygen atom. The remaining incorrect structures used the wrong number of valence electrons.
Two students made a similar incorrect structure as before, with three lone pairs of electrons on oxygen and a double bond. One student placed a single bond between C and O, with one lone pair of electrons on C and three lone pairs of electrons on O. Two other students used only 10 valence electrons and fell short of the octet; one of the students placed the oxygen as the center atom.

Building on Lewis structures, 24 students either drew a trigonal planar shape, described the electron geometry or molecular geometry as trigonal planar or just wrote the words trigonal planar. Building on the shape, 15 students described the bond angle as 120° and 14 students described the molecule as polar. Four students described the shape as tetrahedral, with only one student having a Lewis structure that would lead to the tetrahedral shape. In addition, one student each described the shape as T-shaped or bent.

Valence bond theory was also used to describe the Lewis structure, with eight students identifying sigma or pi bonds in the structure and two students identified sp³ hybridization without attributing it to the central atom. Incorrect applications of the valence bond theory were two students who described the double bond as a pi bond, one student that described the CO bond as sp² and the CH bond as sp and one student who described “the hydrogen bonds are weak and are in s orbital. The double bond is in the p-orbital.”

There were minimal instances of relating this topic to other topics in the course. The most common, seven students correctly identified the molecular mass of the compound. Two students correctly described the electron configurations for individual atoms. Both students also made incorrect electron configurations along with one other student. One of these students attempted an electron configuration for the entire molecule, working with the sum of electrons in the molecule. Using atomic structure, one student correctly described the number of protons and
electrons in hydrogen, though described an incorrect number for oxygen. Another student used periodic trends to correctly describe the relative electron affinity and ionization energy of the atoms in the molecule but incorrectly labeled oxygen as the smallest atomic size. Finally, one student attempted to classify the compound, but incorrectly described it as an ionic compound.

Discussion

In response to the first research question, students’ appear to make a considerable attempt to link chemistry topics in their responses to CEs, particularly between the first two prompts analyzed here. In the first prompt described, each of the categories: stoichiometry, solution chemistry concepts, and gas laws, were well represented in over half of the student responses. There was less use of the nature of chemical compounds. Within each of these broad topics, students used a diverse range of topics, particularly among solution chemistry. In the second prompt described, the majority used thermodynamics and stoichiometry as expected. Nearly half the students used topics in solution chemistry and nearly a quarter used gas laws and the nature of chemical compounds. As the second prompt was a homework CE, which can be thought of as more formative in nature, there is evidence of students frequently linking concepts which can then provide an opportunity for feedback to students on their efforts to link concepts. The CE on molecular shapes featured less variety, as much of the information in General Chemistry on covalent compounds is clustered together in Lewis structures, shapes, and polarity. Still, nearly 1/4 of the respondents used stoichiometry concepts in responding, and by placing a mass of the compound in the prompt it may have spurred greater use of linking these topics.
That students use a wide range of topics in responding to CEs indicates that students can make connections in content throughout the course. That the efforts to link concepts are in response to an open-ended format and not a targeted question indicates that the connections displayed are of the students’ choosing and not an artificial contrivance to address a particular, targeted question. Whether such links are sufficient to enable meaningful learning as described in the Assumptive Learning Theory is yet to be determined. Evidence of long-term retention of the linked concepts would be necessary to claim meaningful learning. This research provides the first step by demonstrating an in-class assessment technique that can serve to identify the links made. Further, the results indicate the potential for future investigations into the use of CEs as an intervention tool to promote greater linking of concepts.

It is also of note that student responses show evidence that students successfully applied the prior and current presented topics in the course to CEs. For the Gas Law CE, among students who attempted to use the topics in terms of conversions, compounds, stoichiometry, and solution chemistry, at least 85% of respondents who attempted to do so, used these concepts correctly. For the thermodynamics CE, there were similar trends when students applied topics of conversions, atomic number, stoichiometry, and solution chemistry. With the molecular shapes CE, the students who attempted connections for topics including atomic number, stoichiometry, Lewis structure, geometry/shape, and valence bond theory were also largely able to make correct statements.

CEs also have the potential to identify students’ misconceptions that can inform instruction during the course of a semester. The most common misconceptions for the Gas Laws CE were to use the ideal gas law to determine moles and to solve for the mass of an aqueous product. Also to incorrectly describe an ionic equation, to identify calcium as a precipitate, and
to incorrectly ascribe simple gas laws to the situations. For thermodynamics, the misconceptions identified often involve mistakes in solving the enthalpy or energy change associated with the reaction, including omitting coefficients or reversing products and reactants when determining the enthalpy of a reaction from heats of formation. Additionally, though less common, students attempted to solve for the energy change of each component in the reaction. Misconceptions were also present in identifying a reactant as a precipitate, applying the Ideal Gas Law where the reaction occurs entirely in solution or attempting to solve the number of FeCl$_2$ atoms or molecules. In molecular shapes, the most common mistakes arise from not solving or incorrectly solving the total number of valence electrons. The resulting erroneous Lewis structure impacts students’ geometry, shapes and polarity determinations. That said, other misconceptions also arose from students misuse of the valence bond theory terms of hybrid orbitals and bond type as well as misconceptions in the structure of the atom in terms of electron configurations or number of protons and electrons.

In response to the second research question, the nature of linked concepts is evident in the detailed description of student responses. One of the most consistent themes present in students’ responses is the misapplication of content when it is applied to a new topic. In both of the first two prompts, a substantial portion of students used the volume of solution in the Ideal Gas Law. While less common in the responses, there is also evidence of applying gas law concepts such as standard temperature and pressure and Avogadro’s Law to the second prompt, which described a reaction occurring entirely in solution. Similarly, students used the term precipitate to describe reactants, and one student response described the hydrogen gas evolved as a precipitate. Other examples of this misapplication were the creation of an electron configuration for an overall
molecule by placing the sum of electrons present in the molecule into the electron configuration for an atom or solving for the atoms of FeCl$_2$.

These results call attention to the need for both instruction and assessment to examine students’ understanding of the limits of models in chemistry. This call corresponds to past research findings that describe the need for incorporating limits of models in teacher preparation and textbooks (Van Driel and Verloop 1999, Justi and Gilbert 2002, Oversby 2000, Dreschler 2007). The student responses demonstrated here represent a possible outcome of failing to incorporate targeted discussions on the limits of models. Additionally, conventional assessment techniques, such as multiple-choice questions, typically do not examine students’ understanding of the limits of models. In particular, designing multiple-choice questions to examine students’ use of existing chemistry concepts with new topics, such as the appropriateness of gas laws for a reaction in solution, is problematic.

CEs can serve as an instrument for uncovering students’ attempted use of concepts with novel topics, but they cannot determine the prevalence of misuse, as they are not directed questions. For example, in the data presented here, it is entirely possible that a large number of students believe the hydrogen gas emitted can be termed a precipitate, but only one student chose to provide that information in their response. One possible way to determine the prevalence of these links in an instructional setting would be to create an assessment similar to the Implicit Information from Lewis Structures Instrument (IILSI) developed by Cooper et al., (2012). Students can be given a single prompt similar to the prompts described above and asked to mark all of the descriptions and procedures that the students believe could be applied. The prompt and student responses associated with 3. 2 were used to develop an example present in Figure 5.
Consider the below situation:

In the reaction: \( \text{FeCl}_2(s) \rightarrow \text{Fe}^{2+}(aq) + 2 \text{Cl}^-(aq) \)

23.0 g of \( \text{FeCl}_2 \) undergoes the reaction in 5.15 L of water initially at 25.0 Celsius (assume 1.0 g / mL).

\( \Delta H_\text{f} \) values:
- \( \Delta H_\text{f}(\text{FeCl}_2) = -341.8 \text{ kJ/mol} \)
- \( \Delta H_\text{f}(\text{Fe}^{2+}) = -87.9 \text{ kJ/mol} \)
- \( \Delta H_\text{f}(\text{Cl}^-) = -167.46 \text{ kJ/mol} \)

Determine if each statement that follows is correct and place a check mark by those that are correct.

- There are 5150 grams of water
- The molar mass of \( \text{FeCl}_2 \) is 126.75 g/mol
- The pressure determined by \( PV = nRT \) is 0.862 atm
- The reaction is a redox reaction
- \( \text{FeCl}_2 \) is the precipitate of the reaction
- The \( \Delta H \) for the reaction is 81.02 kJ/mol
- The reaction is exothermic
- The chloride ion releases more energy than the iron ion in the reaction
- The molarity of chloride ions is 0.0352 M
- The name of \( \text{FeCl}_2 \) is Iron (II) chloride
- \( \text{FeCl}_2 \) is a covalent compound
- The resulting temperature of the water can be determined

\( \text{Figure 5. Example Assessment to Determine Prevalence of Links} \)

Developing and using a series of such assessments would allow instructors to better understand the ability of students to transfer topics appropriately and also facilitate an ongoing in class discussion about the limits of models. Like CEs this proposed assessment can be considered as only a small portion (equal to one or two questions) of a larger assessment. And thus, while a student would have a 50% chance of guessing each statement correctly, a student would have considerably lower odds of scoring highly on the proposed assessment through chance guessing. For example, the odds of guessing 9 or more of the 12 statements correctly would be 7.3%. Future work from this project can involve developing a series of such assessments based on students CE responses and collecting evidence on the validity of these assessments.
Conclusions

Multiple educational theories value the active process of linking concepts to promote meaningful over rote learning. By examining student responses to CEs, it is clear that students can use the assessment technique to show a diverse range of linked concepts within General Chemistry. In addition, the responses also show novel misuse of linking concepts, which calls to light students’ perceptions of the limits of models introduced in this course. The results of this analysis can inform researchers who seek to further investigate the characteristics and traits of meaningful learning or are developing techniques to emphasize meaningful learning in the class. The results inform chemistry teaching on several levels. First, instructors should be aware and emphasize the importance of linking concepts throughout the course. Second, CEs as a mode of assessment will aid in informing instructors about the links students are making, both correctly and incorrectly, as well as emphasizing to students the value placed on making these links. Third, the incorrect responses from CEs can both initiate class discussions regarding the limits of models and the development of a novel assessment technique to measure the same.

Acknowledgments

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References


CHAPTER IV:
DEVELOPING AND IMPLEMENTING AN ASSESSMENT TECHNIQUE TO
MEASURE LINKED CONCEPTS

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Supplementary information for this Chapter can be found in Appendix G.

Introduction

Student learning is aided by the conceptual links that can be made between newly learned content and students’ existing conceptual knowledge. Ausubel’s Assumptive Learning Theory describes meaningful learning as when the learner actively incorporates new knowledge to prior knowledge (Novak, 2010). This is in contrast to rote learning, where new knowledge is memorized in isolation and not connected to other related content. Meaningful learning is further characterized by long-term retention of concepts while rote learning would only yield short-term retention. In considering lasting impact, efforts in education should be directed toward facilitating meaningful learning while minimizing any emphasis on rote learning. Other learning theories or perspectives also emphasize the importance of making connections within course content. First, the Knowledge Integration Perspective emphasizes the importance of
developing a coherent view of scientific phenomena versus the transmission of fragmented scientific knowledge (Linn & Eylon, 2011). Second, deep learning has been operationalized as holistic where knowledge is understood within its context as compared to surface learning which is described as atomistic (Marton & Saljo, 1976). Finally, the description of constructivism emphasizes the match of new concepts with the learner’s previous conceptual knowledge (Staver, 1988). Returning to Assumptive Learning Theory, efforts to promote meaningful learning are supported by assessments that measure students’ understanding of the context of content (Novak, 2010). This paper introduces an attempt to build an assessment designed for large lecture General Chemistry classes that emphasizes the linking of content within General Chemistry.

This work is also informed by diSessa’s contention that students’ knowledge is fragmented and heavily dependent upon context (Disessa, 1998). The assessments proposed seek to provide a method for revisiting prior concepts in different contexts that can allow instructors insight into these perspectives. Also, by placing concepts in different contexts, students can begin to demonstrate a more sophisticated understanding of concepts beyond application in the scenario as presented by instruction and begin to consider application throughout the diverse range of concepts in General Chemistry. This development of a more sophisticated conceptual understanding is in line with Stevens, et al. model of learning progression by further exploring the utility of prior concepts (Stevens et al., 2010).
Background

Developing assessment techniques to match educational goals is an important area for multiple reasons. First, students direct their efforts toward how they are assessed (Crooks, 1988). Thus, an assessment technique that emphasizes linking new concepts with existing concepts has the potential to promote students’ efforts to do the same while reinforcing an instructor’s efforts to facilitate such linking. Second, assessments serve as the primary vehicle by which instructors learn about students’ conceptions (NRC, 2003). By building an assessment that emphasizes linking concepts, instructors can better understand the effectiveness of their instructional efforts to achieve this goal. Third, assessments provide feedback to the students regarding their progress in the course. By incorporating questions related to the linking of concepts, students can better understand their own progress on building these links.

The most widely known assessment technique for linking concepts is concept maps. Concept maps were originally proposed by Novak as a research tool to investigate student conceptions, and they have subsequently been used as a classroom assessment technique (Novak & Gowin, 1984). In a concept map, students are tasked with linking two concepts with an arrow and a proposition, a single word or short phrase that describes the nature of the link of the two concepts. As an assessment technique, there is considerable variety in terms of administration methods and scoring techniques (Lewis et al., 2011). Some scoring techniques emphasize the organization of concepts and the extent hierarchies are present while others focus primarily on the validity of the propositions presented (Novak & Gowin, 1984; Francisco et al., 2002).

Another assessment technique designed to promote linking of concepts is Creative Exercises (Lewis et al., 2011; Trigwell & Sleet, 1990). Creative Exercises involve providing a prompt to students that describes a chemical situation, such as the “oxidation of 25.0 grams of
Students are encouraged to write down as many statements as they can that are relevant to the prompt and the material covered in class. Students are scored based on the number of correct and distinct statements they can create. Investigating student responses to a set of Creative Exercises showed that student responses were able to describe a wide range of chemistry content related to each prompt (Ye & Lewis, 2014). It is inferred that students’ ability to do so is representative of the links they form among the content in General Chemistry.

Concept maps and Creative Exercises are necessarily open-ended assessment techniques, defined as assessments that have more than one or a small set of possible right answers. Students respond to open-ended assessment based on the information they deem most relevant and each student can have drastically different responses to a single prompt and each may score well on the assessment. There are many advantages with an open-ended set-up that include learning the information that the student deems most relevant and providing the student the opportunity to organize information in the student’s response to the assessment.

However, there are some drawbacks to open-ended assessments. First, they cannot target a particular concept. If, for example, an instructor wanted information on students’ understanding of electron configurations as they relate to quantum numbers, an open-ended assessment can provide some evidence for those students who chose to show this link. For students who choose to provide alternative information (e.g. relate electron configurations to chemical reactivity instead), little can be concluded regarding these students’ understanding of the link to quantum numbers. Second, open-ended assessments cannot provide information on the prevalence of concepts. For example, in Creative Exercises it was found that students would incorrectly use the ideal gas law on chemicals that were not in the gaseous state (Ye & Lewis, 2014). While a sub-set of students indicated this incorrect link of concepts, it is not known how
widespread this incorrect link is among students. Finally, as an open-ended assessment, grading
can become logistically problematic for very large classes or assessing multiple classes, in
particular when the assessment technique is regularly used.

Creating a series of closed-ended assessments that measure students’ abilities to assess
the linking of concepts within a course can address these drawbacks. Such a closed-ended
assessment loses the student generation of links, which can only be achieved with open-ended
assessments. Closed-ended assessments also have limitations in that students can be scored
correctly through chance, by guessing the correct answer. Additionally, in closed-ended
questions, students may identify a correct answer through test-taking strategies unrelated to
conceptual understanding or select a correct or incorrect answer for a different reason than the
instructor’s intent (Graulich, 2014; Towns, 2014). However, closed-ended assessments can target
specific concepts and thus have the ability to determine the prevalence of students’
understanding of these concepts. Closed-ended assessments can also benefit from automated
grading that facilitates implementation in large classes or across multiple classes and minimizes
the potential for grader error. The goal of this article is to present closed-ended assessments
designed to measure the linking of concepts as a potentially useful instructional tool in
chemistry. Toward that end, this article will describe the methodology in developing and
administering the assessments and discuss student results from the assessment in terms of
instructional implications.
Methodology

To develop an assessment that measures the prevalence of students’ abilities to link specific concepts a series of closed-ended assessments, termed Measure of Linked Concepts (MLCs), have been developed. In this work, the term concept follows Taber’s perspective of conceptual knowledge as any knowledge that is meaningful (Taber, 2014). Meaningful knowledge has an explanatory value that is often shown by describing the relationships to other content and is opposed to learning facts in isolation. In this method, stoichiometry can be learned in isolation as a memorized algorithm, but becomes conceptual when students can understand the value of stoichiometry in a range of situations. The term linking then is used to describe the relationships between concepts. In this case the linking occurs in content throughout the course of General Chemistry though linking with students’ everyday experiences and content knowledge in other courses are certainly fruitful areas for researchers to explore. The MLCs then are designed to measure the extent students can link a newly learned target concept with prior concepts throughout the course.

The design of an MLC is to provide an initial description of a chemical situation to students similar to the design of Creative Exercises (Lewis, 2011). Next, students are given a series of statements that are related to the prompt that span the content of the course. The statements are based on student responses to Creative Exercises that have been collected in previous research and can be either correct or incorrect links of content (Ye & Lewis, 2014). The statements are also designed to span the content of previous topics in the course. Six instructors of General Chemistry reviewed the MLCs presented here prior to their use in exams. Instructors who are interested in designing their own MLCs would be encouraged to use learning objectives associated with each major topic (e.g. chapter in the textbook) and attempt to have at
least one statement per major topic. Students are given instructions to evaluate each link as either true or false, in essence providing students a task very similar to grading another student’s response to a Creative Exercise. The MLC also has the benefit of incorporating material learned earlier in the course (e.g. before the previous test), which rewards students for retaining information throughout the course. MLCs can be used in a variety of instructional contexts such as activities within group work, as homework or part of an exam. When the MLC is incorporated within a traditional assessment it is recommended that each statement is given less weight than the conventional test questions owing to the higher likelihood of guessing correctly with true/false statements. In the results discussed below, each MLC statement is rated as either one-third or one-half the weight of a single multiple-choice question. Instructors who are concerned about the higher likelihood of guessing correctly may consider offering students a third answer choice of “I’m not sure” where students who select it receive partial credit on the question (e.g. one-third of the points possible).

An example of an MLC with the instructions given to students is shown in Figure 6. One MLC each was incorporated into four homework assignments and four in-class tests throughout a semester of General Chemistry I at a large university. At the setting 1,653 students initially enrolled in General Chemistry I and the exams were administered at a common time for all students. For the homework assignments, an MLC was written into the Sapling Learning online homework system and the homework assignments were staggered such that students saw one MLC prior to each test. This was done to familiarize students with the assessment technique prior to seeing MLCs on the in-class tests, which serve as high stakes assessments in terms of course grades. Students were permitted up to ten attempts on each of the homework MLCs and
received credit if they answered all of the prompts correctly. Alternatively, students could choose to view the solution to the homework MLC and would then not receive any credit.

Consider an atom of sulfur. Indicate whether each statement about an atom of sulfur is true (A) or false (B).

1. It is more likely to gain electrons than silicon
2. Its last electron is found in an ‘s’ orbital
3. It has an electron in m_s = +1/3
4. The greater number of protons in its nucleus causes a sulfur atom to be larger than an aluminum atom
5. It has 6 valence electrons
6. Has a higher tendency to lose electrons than magnesium
7. Sufficiently bright light below the threshold frequency will cause an electron to be emitted

**Figure 6.** Example of an MLC Used within an Exam

**Results and Discussion**

The results from the four MLCs given as in-class tests are presented in Tables 6 through 9. The four homework MLCs are presented as a supplementary document in Appendix G. The curriculum follows an atoms-first approach where the content first introduces the structure of the atom, quantum numbers, electron configurations and periodic trends for the first in-class test. On this in-class test, the corresponding MLC1 is presented in Table 6. In the content for the next in-class test, models of bonding are introduced with an emphasis on covalent bonds, Lewis structures, molecular shapes and polarity, with the corresponding MLC2 described in Table 7. Following this are thermodynamics, the Born-Haber ionic bonding model, gas laws and intermolecular forces (MLC3 in Table 8). The last topics covered are solid-state chemistry, units of solution concentration and colligative properties (MLC4 in Table 9). This curriculum assumes prior knowledge of atomic structure, nomenclature, stoichiometry and reactions in solution from previous chemistry courses. MLCs could be developed for additional curricular
models focusing on the content previously covered in the course at each assessment. Within each MLC, the intention was to link each statement with the prompt but to avoid statements that were dependent on other statements so that students missing one statement would not necessarily miss others (Towns, 2014).

Table 6. MLC1

<table>
<thead>
<tr>
<th>Prompt: An atom of Sulfur</th>
<th>Statements (Correct Answer)</th>
<th>Correct Responses, %</th>
<th>Correlation with Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 It is more likely to gain electrons than silicon (True)</td>
<td>87%</td>
<td>0.600</td>
</tr>
<tr>
<td></td>
<td>2 Its last electron is found in an ‘s’ orbital (False)</td>
<td>97%</td>
<td>0.297</td>
</tr>
<tr>
<td></td>
<td>3 It has an electron in m, = +1/3 (False)</td>
<td>97%</td>
<td>0.230</td>
</tr>
<tr>
<td></td>
<td>4 The greater number of protons in its nucleus causes a sulfur atom to be larger than an aluminum atom (False)</td>
<td>72%</td>
<td>0.563</td>
</tr>
<tr>
<td></td>
<td>5 It has 6 valence electrons (True)</td>
<td>93%</td>
<td>0.432</td>
</tr>
<tr>
<td></td>
<td>6 Has a higher tendency to lose electrons than magnesium (False)</td>
<td>79%</td>
<td>0.580</td>
</tr>
<tr>
<td></td>
<td>7 Sufficiently bright light below the threshold frequency will cause an electron to be emitted (False)</td>
<td>69%</td>
<td>0.557</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>85%</strong></td>
<td></td>
</tr>
</tbody>
</table>

^N = 1587

Table 7. MLC2

<table>
<thead>
<tr>
<th>Prompt: A molecule of PCl₅</th>
<th>Statements (Correct Answer)</th>
<th>Correct Responses, %</th>
<th>Correlation with Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 PCl₅ is phosphorus pentachloride (True)</td>
<td>96%</td>
<td>0.224</td>
</tr>
<tr>
<td></td>
<td>2 The molecule has sp³ hybridization (False)</td>
<td>93%</td>
<td>0.375</td>
</tr>
<tr>
<td></td>
<td>3 When the preferred Lewis structure is drawn, no lone pairs appears on P (True)</td>
<td>93%</td>
<td>0.429</td>
</tr>
<tr>
<td></td>
<td>4 The bond between P and Cl is polar (True)</td>
<td>82%</td>
<td>0.360</td>
</tr>
<tr>
<td></td>
<td>5 Cl has a larger atomic radius than P (False)</td>
<td>67%</td>
<td>0.536</td>
</tr>
<tr>
<td></td>
<td>6 Its electron configuration is 1s² 2s² 2p⁶ 3s² 3p⁶ 4s² 3d¹⁰ 4p⁶ 5s² 4d² (False)</td>
<td>52%</td>
<td>0.328</td>
</tr>
<tr>
<td></td>
<td>7 Its molecular geometry is trigonal bipyramidal (True)</td>
<td>89%</td>
<td>0.437</td>
</tr>
<tr>
<td></td>
<td>8 PCl₅ is a polar molecule (False)</td>
<td>59%</td>
<td>0.435</td>
</tr>
<tr>
<td></td>
<td>9 Cl has higher first ionization energy than P (True)</td>
<td>78%</td>
<td>0.382</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>79%</strong></td>
<td></td>
</tr>
</tbody>
</table>

^N = 1533

61
Table 8. MLC3

<table>
<thead>
<tr>
<th>Statements (Correct Answer)</th>
<th>Correct Responses, %&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Correlation with Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The reaction is exothermic (True)</td>
<td>76%</td>
</tr>
<tr>
<td>2</td>
<td>ZnCl&lt;sub&gt;2&lt;/sub&gt; is zinc dichloride (False)</td>
<td>19%</td>
</tr>
<tr>
<td>3</td>
<td>ZnCl&lt;sub&gt;2&lt;/sub&gt; is a covalent compound (False)</td>
<td>63%</td>
</tr>
<tr>
<td>4</td>
<td>ΔH for the reaction is -72.22 kJ/mol (True)</td>
<td>56%</td>
</tr>
<tr>
<td>5</td>
<td>The pressure determined by PV = nRT is 0.684 atm (False)</td>
<td>31%</td>
</tr>
<tr>
<td>6</td>
<td>The electron configuration of Zn&lt;sup&gt;2+&lt;/sup&gt; is [Ar] 3d&lt;sup&gt;10&lt;/sup&gt; (True)</td>
<td>54%</td>
</tr>
<tr>
<td>7</td>
<td>Ion-dipole interactions are present in the products (True)</td>
<td>71%</td>
</tr>
<tr>
<td>8</td>
<td>The molar mass of ZnCl&lt;sub&gt;2&lt;/sub&gt; is 136.3 g/mol (True)</td>
<td>95%</td>
</tr>
<tr>
<td>9</td>
<td>After the reaction, the temperature of the surrounding water will be less than 25.0°C. (False)</td>
<td>66%</td>
</tr>
<tr>
<td>10</td>
<td>A neutral Cl atom has a greater atomic radius than a neutral Zn atom (False)</td>
<td>79%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>N = 1419

Table 9. MLC4

<table>
<thead>
<tr>
<th>Statements (Correct Answer)</th>
<th>Correct Responses, %&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Correlation with Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ion-dipole interactions are present in the solution (True)</td>
<td>78%</td>
</tr>
<tr>
<td>2</td>
<td>The boiling point of the solution is 70.9°C (True)</td>
<td>48%</td>
</tr>
<tr>
<td>3</td>
<td>The pressure equals 0.215 atm (False)</td>
<td>71%</td>
</tr>
<tr>
<td>4</td>
<td>The carbon in CH&lt;sub&gt;3&lt;/sub&gt;OH is sp&lt;sup&gt;3&lt;/sup&gt; hybridized (True)</td>
<td>87%</td>
</tr>
<tr>
<td>5</td>
<td>In the preferred Lewis structure of CH&lt;sub&gt;3&lt;/sub&gt;OH, oxygen has a formal charge of -1 (False)</td>
<td>75%</td>
</tr>
<tr>
<td>6</td>
<td>NaBr dissociates to form Na&lt;sup&gt;+&lt;/sup&gt; and Br&lt;sup&gt;-&lt;/sup&gt; (False)</td>
<td>73%</td>
</tr>
<tr>
<td>7</td>
<td>CH&lt;sub&gt;3&lt;/sub&gt;OH contains nonpolar bonds but is a polar molecule (True)</td>
<td>68%</td>
</tr>
<tr>
<td>8</td>
<td>An atom of sodium has greater electron affinity than bromine (False)</td>
<td>69%</td>
</tr>
</tbody>
</table>

62
<table>
<thead>
<tr>
<th></th>
<th>( \Delta H_{\text{solvent}} ) arises from the hydrogen bonding between methanol molecules (True)</th>
<th>71%</th>
<th>0.337</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>71%</td>
<td></td>
</tr>
</tbody>
</table>

\(^*N = 1354\)

**Table 10.** Percent correct of statements in MLCs divided by “True” or “False”

<table>
<thead>
<tr>
<th>MLC</th>
<th>“True” (N(^a))</th>
<th>“False” (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLC 1</td>
<td>90 % (2)</td>
<td>83 % (5)</td>
</tr>
<tr>
<td>MLC 2</td>
<td>87 % (4)</td>
<td>54 % (5)</td>
</tr>
<tr>
<td>MLC 3</td>
<td>70 % (4)</td>
<td>43 % (6)</td>
</tr>
<tr>
<td>MLC 4</td>
<td>70 % (5)</td>
<td>72 % (4)</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>79 %</td>
<td>63 %</td>
</tr>
</tbody>
</table>

\(^aN \text{ represents the number of statements that are “True” or “False”}\)

The content in MLC1 (Table 6) necessarily has less linked content throughout the course given its early placement in the semester, still as one assessment it can incorporate numerous concepts related to quantum numbers and periodic trends. Student results indicate high performance with many of the statements, but students had less success with the MLC1 statements related to periodic trends (statements 4 and statement 6, abbreviated MLC1.4 and MLC1.6 respectively) and the photoelectric effect (MLC1.7). In Table 7, the building of the content becomes more evident as MLC2.5 and MLC2.9 relate to periodic trends and statement 6 relates to electron configurations. MLC2.6 describes an electron configuration for \( \text{PCl}_5 \) using the number of valence electrons. As 48% of students incorrectly assigned the statement as true, there is an indication that students do not understand the limits of the model for electron configuration. This phenomenon is analogous to the generalization heuristic where students recognize patterns but not the conditions in which the pattern is applicable (Talanquer, 2014). It may be expected that the introduction of valence bond theory, in particular orbital hybridization, may make the case, directly or indirectly, that electrons in molecules are not building within the
same electron configuration. The results indicate this is not the case. In contrast 93% of the students were able to correctly evaluate the hybrid orbital given in MLC2.2 regarding the same molecule. Thus it appears students are able to employ the algorithm presented regarding orbital hybridization, they are considerably less likely to understand the implications this model has for electron configurations. It is also worth noting that students saw a similar statement on electron configurations in molecules in the preceding Sapling HW assignment HWMLC2.5 (see Appendix G).

The MLC presented in Table 8 occurs later in the term and targets a range of concepts including thermodynamics (MLC3.1, MLC3.4 and MLC3.9), nomenclature (MLC3.2), models of bonding (MLC3.3), gas laws (MLC3.5), intermolecular forces (MLC3.7), electron configurations (MLC3.6), stoichiometry (MLC3.8) and periodic trends (MLC3.10). The revisiting of multiple concepts within a single assessment given later in the term can reward students for retaining earlier information as described earlier. The percent correct on nomenclature (19%) is the lowest among any of the MLC statements. As mentioned, nomenclature was not covered specifically in this course; instead it was assumed that students would enter the course with this knowledge well established from preceding courses. The low percent correct make this assumption questionable and may call for revisiting it. MLC3.5 on gas laws further explores student understanding of the limits of models. The prompt provides information on volume and temperature of water and moles of a compound, though none of the compounds present are in the gas phase. The majority of students (69%) described this prompt as true, which matches the review of student responses to Creative Exercises where the use of gas laws in incorrect situations was prevalent. Past research has called for instruction to explicitly
address the limits of models (Justi & Gilbert, 2002), but it appears prudent to also recommend assessment practices, such as MLCs, that measure student understanding of the limits of models.

In Table 9, this MLC was given as part of a cumulative final exam in the course. The emphasis at the end of the semester was on colligative properties (MLC4.2) and the model for solution formation (MLC4.1 and MLC4.9). MLC4.6 was also related to colligative properties given the emphasis on writing dissociation reactions in understanding the Van’t Hoff factor. This MLC also covered gas laws (MLC4.3), Lewis structures (MLC4.5), polarity (MLC4.7), valence bond theory (MLC4.4) and periodic trends (MLC4.8). The use of gas laws was meant to further investigate the student performance on the previous MLC. Students performed better on this statement and the chi-square test showed no association between how students performed on MLC3.5 versus MLC4.3 ($\chi^2 = 0.896$, Cohen’s $w = 0.03$ indicating a negligible effect size). This may be a result of the difference in prompts as the MLC4.3 prompt includes STP conditions and does not include a volume that may alter the response pattern.

Also present in Tables 6 through 9 are the correlations of students’ responses on each statement (scored 0 for incorrect, 1 for correct) to the students’ total score on the corresponding MLC. This correlation can be referred to as the discrimination index, which describes the extent student performance on a particular statement is related to their performance on the set of statements in the MLC. Of the 35 statements, nearly half (17 statements) had discrimination indices above 0.4 and the strong majority (28 statements) was over 0.3. Of the seven statements that were below 0.3, three statements approached or were below the 0.2 cut-off suggested for removing the statement (MLC1.3, MLC2.1 and MLC3.8) (Towns, 2014). Each of the three had percent correct greater than 95%, which is the likely reason for the low correlation value. The correlations overall indicate that the strong majority of statements are providing appropriate
discriminatory ability, with the suggestion that future iterations may benefit by revising or removing the three statements indicated. To examine whether the answers of statements in MLCs have influence on the percent correct for students, Table 10 describes the percent correct of statements in MLCs when they were “True” or “False”. The results indicated that the “True” statements had relatively higher percent correct on MLCs than the “False” statements, 16% higher on average. Future studies examine the relationship between the answers of statements and student performance on MLCs is worthwhile to be investigated.

The use of MLCs also offers an opportunity for instructors to discuss well-known misconceptions that may be difficult to introduce with traditional assessment. For example, research has shown that students over rely on the octet rule as an explanation for ion formation instead of electrostatics (Table, 2001). In MLC4, statement 8 provides a means for considering periodic trends in electron affinity while describing a situation with an ionic compound. Follow-up instruction could describe why the relative ionization energy and electron affinity values for Na and Br are important considerations in an ionic compound to emphasize the importance of electrostatic interactions. Similarly, research has shown student confusion between molecular and ionic compounds, in particular ascribing molecular structure to ionic compounds (Taber, 2012). This misconception is explored directly in the homework HWMLC3, statement 5. The importance of distinguishing between ionic and molecular compounds is present throughout the MLCs in terms of nomenclature (MLC2.1, MLC3.2, HWMLC2.2, HWMLC3.3 and HWMLC4.3), structure of molecule or ion (MLC2.3, HWMLC2.1, HWMLC3.5 and HWMLC4.5) and in terms of classification (MLC3.3).
Limitations and Future Work

This article is intended to present MLCs as a method of student assessment that can provide instructors information on the prevalence of linked concepts. At the current setting the incorporation of MLCs has provided insight into student understanding of a variety of concepts throughout the course such as student understanding of the limits of models. Toward that end, MLCs are recommended as a potential tool in the assessment toolbox for instructors to incorporate within their own assessment methods. However, it should be pointed out that each statement represents only a single measure of the relevant concept. Additionally, there is the potential that correct responses to the MLCs may reflect a heuristic or shortcut that the student is employing rather than a robust understanding of chemical principles (Graulich, 2014). For instructional purposes, it is therefore recommended that student assessments use a variety of assessment techniques where MLCs can serve as one such technique.

Ongoing and future work will investigate the ability of MLCs to achieve the goal of promoting and measuring the linking of content throughout the course. First, research investigating the validity of MLCs as a measure of linking content is necessary. Such research will involve investigating the response process of students undertaking MLCs and examining the relationship between MLCs and other measures of linked concepts such as Creative Exercises or Concept Maps. In particular some of the statements in the MLC can be evaluated without the original prompt (e.g. MLC2.5, MLC2.9, MLC3.2, MLC3.3, MLC3.6 and MLC4.5). It may be that students evaluating these statements within the broader context is sufficient to make the link clear to students or these statements may continue to be evaluated as independent statements and no linkage is made. Future research is needed to clarify the extent linking occurs with these
statements. Also, validity would be aided by having sub-discipline content experts evaluate the phrasing of each statement.

Second, if sufficient evidence for validity is found, the ability of MLCs to promote linking of concepts can be explored. If successful, Assumptive Learning Theory suggests that the practice of assessing the linking of content can lead to more meaningful learning that would be demonstrated through greater long-term retention. Research into the role of these assessments in promoting long-term concept retention would serve to provide validity for the theory and offer greater utility to the assessment technique. Future work can also investigate the impact of incorporating MLCs into course assessments on students’ efforts in course preparation or the impact of MLCs in cooperative learning on student group discussion.

Conclusions

The use of MLCs in the General Chemistry class has provided insight into the prevalence of students’ concepts and has informed instruction at the research setting. The intent of this article is for instructors to consider students’ efforts to link content, in particular in the development of assessments, given the importance of these connections in learning theories. MLCs have the potential to serve as an assessment technique in this role and may be considered along with Concept Maps or Creative Exercises. Among these techniques, MLCs is unique in identifying the prevalence of student concepts by requiring each student to evaluate each connection and has the potential to meet the logistic demands of large classes, which are common in post-secondary introductory chemistry courses.
Acknowledgments

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References


CHAPTER V:
LEARNING BEYOND THE CLASSROOM: USING TEXT MESSAGES TO MEASURE GENERAL CHEMISTRY STUDENTS’ STUDY HABITS

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Introduction

Understanding factors related to student learning in General Chemistry is necessary to design and evaluate implementations to improve academic performance. Considerable effort has been made toward this end through the use of reformed pedagogical techniques. These techniques target in-class activities and have shown a notable impact on metrics for academic performance (Freeman et al., 2014). In post-secondary education however, students spend only three to five hours per week in class with the opportunity to spend considerably more time outside of class studying the course materials. This leads to two overlapping possibilities regarding a causal explanation for the effectiveness of in-class pedagogical reform: i) students’ experiences in class cause learning gains or ii) the reform modifies students’ activities outside of class that cause learning gains. Currently little information is known regarding post-secondary chemistry students’ studying of course material outside of class, herein referred to as study
habits. This study seeks to examine a novel method for measuring students’ study habits and explore the role of study habits in academic performance.

Background

Past Work on Study Habits

Considerable past work on college students’ study habits has been carried out in the fields of education and psychology. In a recent meta-analysis of the work on study habits, Crede and Kuncel (2008) described the empirical and theoretical literature on studying behaviors as fragmented. They organized studying behaviors based on the constructs: *study skills*, knowing how to study, *study habits*, the frequency and type of actions taken toward studying and *study attitudes*, the motivation toward studying. These constructs are differentiated from study processes that describe the depth of processing on a continuum from deep (an effort to relate new material to previously learned contexts) to surface (characterized as memorization without seeking context). In the meta-analysis, the researchers identified 40 studies relating study habits to college GPA and found correlations that average approximately 0.33 with a 90% interval between 0.09 and 0.51. Relationships between study habits and individual course performance was lower, averaging 0.26, which the authors attribute to not being able to correct for reliability in individual course grades. Study habits also featured a weak relationship with established measures of general cognitive ability such as high school GPA or college admissions tests. This suggests that the relationship between study habits and academic college performance is unique from the well-established relationships between measures of cognitive ability and student
performance. Further, it helps to rule out the explanation that stronger students exhibit better study habits and that this is responsible for the observed correlation; instead it suggests that students can benefit from effective study habits regardless of incoming ability.

There has been little research attention toward measuring study habits in the context of post-secondary chemistry. Richards-Babb and Jackson (2011) investigated gender differences in study habits through a survey given at the end of General Chemistry and reported that male students were more likely to procrastinate. Also related, Li et al. (2013) investigated post-secondary chemistry students’ conceptions of learning chemistry and approaches to learning chemistry. Conceptions of learning chemistry were measured by a survey developed based on earlier, more general research interviewing students about learning experiences. This work identified memorizing, testing, calculating / practicing and higher order thinking labeled as transforming as the relevant themes in students’ conceptions of learning. Approaches to learning were measured based on the previously described study processes and the continuum from surface to deep learning. The study found that students who were characterized as deep learners conceived of learning in multiple ways including transforming, memorizing and testing, while learners that used surface strategy employ memorizing and testing.

Most studies that investigated students’ study habits used a single-admission survey that may be problematic for two reasons. First, as a single measure, it presumes that students’ study habits are constant, whereas it is possible that students’ study habits adapt to the nature of the content and with familiarity toward assessment expectations. Second, as an in-class survey, it relies upon retrospection on behalf of the student, particularly when it is given at the end of the semester. Past research has called into question the accuracy of retrospective accounts, particularly at lengthier time intervals (Bernard et al., 1984). By exploring study habits at
multiple time points, both problems may be minimized as changes over time can be documented and participants would not be asked to reflect upon several months of study habits.

There have also been efforts made to improve students’ study habits. Cook et al. (2013) implemented a one-day lecture for General Chemistry students that presented differences in expectations between post-secondary and secondary education as described by Bloom’s taxonomy. They also presented metacognitive learning tools including a study cycle. At the conclusion, students made a brief written statement committing to use some of the tools presented. Student attendance to the lecture was voluntary though students received a bonus equivalent to 0.5% of their grade for attending. Attending students were compared to non-attendees on the metric of points earned in the course post-implementation (transformed to follow a normal distribution). The statistical comparison used students’ first exam score as a covariate as it preceded the implementation. The results of an ANCOVA showed that students who attended the treatment performed better on the outcome measure than those who did not. These results indicate the potential importance of student study habits to student learning, but the results could also be indicative of a confounding variable such as student motivation. For example, the authors did note that the control group missed more exams than the treatment group and that could be an indication that the groups differed in their motivation to succeed in the class. Incorporating a measure of study habits before and after the intervention would further elucidate the impact of the intervention and help better establish a causal connection such as the intervention impacted student study habits which led to greater student learning.

In summary, considerable research has shown a relationship between study habits and academic performance in post-secondary education but not in the sciences. The following study seeks to address this gap in the research literature by investigating the frequency and types of
study habits in General Chemistry. The creation of a detailed measure of student study habits as described below can open two potentially fruitful areas of study. First, measuring study habits can inform efforts to better understand the factors related to academic success (study habits as an independent variable). Second, measuring study habits can aid explorations of instructional efforts to improve students’ study habits (study habits as a dependent variable). The following study takes an exploratory approach to examine study habits as an independent variable.

**Experience Sampling Method**

The methodology used in this study is Experience Sampling Method (ESM) which uses technology to measure participants’ self-report of their actions or psychological state while the participant is in their natural environment. What follows is a brief summary of the methodology as it applies to the current study. For a complete introduction to Experience Sampling Method (ESM) including methodological stance, research antecedents and examples, readers are advised to please see Hektner *et al.* (2007). By measuring in the participant’s natural environment, researchers can learn about participants’ actions outside of a particular research setting (e.g. the classroom) while relying on a much more proximal retrospective account than traditionally done. ESM has been described as systemic phenomenography in that the information collected relies on self-report and remains restricted to describing the participants’ perspective on the area of focus. It is considered systemic in that ESM uses technology to facilitate multiple measures of a construct from each participant to establish reliability and investigate patterns within a participant.

ESM has been used in a variety of contexts, particularly in the field of psychology where it has been used to explore constructs as diverse as morality, mental illness and substance
abuse. (Hoffman et al., 2014; Smyth and Stone, 2003) It has also been used with medical applications to investigate disorders, drug abuse and treatment effectiveness. (Hektner et al., 2007) In education it has been used most often at the secondary level to investigate student motivation, satisfaction with the educational environment or the nature of the environment. (Csikszentmihalyi, 2014) To date, we could not locate a study that has used ESM to explore a post-secondary chemistry setting or post-secondary student study habits.

Research Questions

As ESM has not been previously used to explore post-secondary study habits, the first research goal was to establish the utility of this method to measure post-secondary students’ study habits. Additional research goals include relating study habits to academic performance, which speaks to the relative importance of study habits, and investigating the extent study habits change. If study habits are found to change over the semester, this would suggest a fruitful line of research to investigate instructional actions to direct student study habits toward effective practices. Specifically, this study was guided by the following research questions:

1a. To what extent is it feasible to measure student study habits using ESM?

1b. To what extent is there evidence for the validity of the data collected on student study habits?

2. Which study habits were related to academic performance in the course as measured by a cumulative final exam?

3. How did student study habits change over the course of the semester?
Research Setting

This study was conducted over one semester at a large research-intensive university in the southeast United States. At the setting four classes of General Chemistry were offered with class sizes between 200 and 225 students. The classes are coordinated where the instructors agree to a common syllabus, textbook, grading scheme, content sequence and pace. The classes also employed common exams where students across all classes take the same exam at the same time. The exams were constructed by contributions from each of the four instructors and used multiple-choice questions and a measure of linked concepts (Ye and Lewis, 2014). The measure of linked concepts provides a brief description of a chemical situation and has students evaluate the legitimacy of a series of statements as true or false. The series of statements span the content throughout the course and are meant to have students consider how concepts throughout the course are linked.

To aid student studying, past exams were posted approximately two weeks before the actual exam and are referred to as practice tests. The textbook used was Tro’s Chemistry: A Molecular Approach (2014) and the content sequence was: quantum numbers, periodic trends, Lewis structures, shapes and polarity, gas laws, thermodynamics, intermolecular forces and properties of solutions. Grades were determined largely by performance on three in-class exams (15% each) and the cumulative final exam (25%). A smaller portion of the grade was attributed to three different effort-based measures at 10% each. First, the class used weekly peer-led problem-solving sessions where students worked in groups on problems designed by the instructors with the aid of peer-leaders (Lewis, 2011). Attendance and participation in these sessions was worth 10% of their grade. Second, students were graded on their performance on
eight online homework assignments using Sapling Learning. Third, instructors used clickers to facilitate in-class questions in the large lecture-hall setting.

**Methods**

Students were recruited for this study from three of the four General Chemistry classes at the research setting. One class was omitted from this study as the instructor for the class was a member of the research team, and there was concern that recruitment might appear coercive to students. Among the three classes that were recruited, 670 students were enrolled (out of 889 students among the four classes). Recruitment occurred on the first day of class by describing the nature of participation in this study. Participants would be asked for their cell phone number and would periodically receive a text message that inquired “Have you studied for General Chemistry I in the past 48 hours? If so, how did you study?” The text messages would be sent approximately twice a week at random times between 9 AM and 9 PM. Participants would be asked to respond to the message within 12 hours of receipt if possible and were given an instruction sheet that included example responses. To encourage participation, students who responded to 80% or more of the text messages would be entered into a raffle for a $25 gift card at the end of the semester. The university’s Institutional Review Board approved these procedures. The recruitment effort led to 301 participants consenting of the 670 students (44.9%). The text message inquiry was sent out as described above 28 times over the course of the semester.

Student responses to the text messages were combined with data collected in the normal educational setting from either university records or in-class records. This data includes student
responses to the revised two-factor Study Process Questionnaire (rSPQ) administered on the first day of class (Biggs, 2001). The rSPQ is a 20 item Likert-scale instrument meant to measure students’ study processes. The instrument was revised by the original instrument’s author and measures respondents on two sub-scales: deep approach and surface approach. The deep approach can be characterized by intrinsic interest or a motivation to understand. Example items from the rSPQ that measure the deep approach are “I come to most classes with questions in mind that I want answering” and “I find that at time studying gives me a feeling of deep personal satisfaction.” The surface approach can be characterized by a narrow focus on content and memorization with example statements “My aim is to pass the course while doing as little work as possible” and “I find the best way to pass examinations is to try to remember answers to likely questions.” In this study, students were asked to consider their study habits in general, but if they need to consider a subject, consider how they would study for chemistry or a science course. The Likert-scale was a five-point range from “this item is never or only rarely true of me” to “this item is always or almost always true of me,” and each factor score represents the sum of ten associated items.

In this study the rSPQ is thought to measure the quality of studying where the deep approach describes the desirable educational process (Biggs 2001). This is differentiated from study habits, which describe the type and frequency of studying. There are expected relationships between the constructs, for example students who employ a deep approach are expected to study more frequently. Student scores on the rSPQ are considered in contrast to their cohort as recommended by Biggs (2001). Additional measures include student demographics and SAT scores (a measure of incoming college preparation) from university records, and student performance on exams from in-class records. Descriptive statistics on each of these measures for
the population of 899 students are presented in Table 11.

**Table 11. Descriptive Statistics of Measures**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average</th>
<th>St. Dev.</th>
<th>N</th>
<th>Theoretical Range</th>
<th>Cronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAT Math</td>
<td>552</td>
<td>68</td>
<td>695</td>
<td>[200, 800]</td>
<td></td>
</tr>
<tr>
<td>SAT Verbal</td>
<td>548</td>
<td>73</td>
<td>695</td>
<td>[200, 800]</td>
<td></td>
</tr>
<tr>
<td>Deep Approach</td>
<td>32.1</td>
<td>6.7</td>
<td>797</td>
<td>[10, 50]</td>
<td>0.826</td>
</tr>
<tr>
<td>Surface Approach</td>
<td>23.8</td>
<td>6.2</td>
<td>797</td>
<td>[10, 50]</td>
<td>0.776</td>
</tr>
<tr>
<td>Final Exam</td>
<td>48.5</td>
<td>15.7</td>
<td>754</td>
<td>[0, 100]</td>
<td>0.816</td>
</tr>
</tbody>
</table>

**Results and Discussion**

**Feasibility of ESM for Measuring Study Habits**

Over the course of the semester 4,775 responses were collected in response to the 28 inquiries. This represents an average of approximately 16 responses per participant. A histogram of the frequency of student responses is presented in Figure 7. From the histogram, there were 34 students (11.3% of participants) who never responded to the text message inquiries. There were also a sizable number of students who regularly responded, as 188 students (62.5%) responded to at least half of the messages and 137 students (45.5%) responded to at least three-quarters of the messages.
In terms of feasibility, it is plausible to have a substantial portion of the recruited population respond to this data collection technique. It is worth noting that the raffle incentive required responses to 80% of the inquiries (23 or more inquiries), which may partially explain the rise in number of participants who responded to 23 or more inquiries. Instead, the largest source of data attrition in the study was during the initial recruitment, where out of an initial population of 670 students, 301 students agreed to participate (44.9%). This suggests that future research studies that intend to rely on a large number of responses would benefit by planning for a substantially larger recruitment pool. The current data indicates that roughly one-quarter of the initially recruited population provided responses to at least half of the inquiries.

At the close of the semester, an additional text message inquiry was sent asking participants if they would participate in a similar study using text messages in the future. Of the 94 respondents, 78% responded positively compared to 18% negative (with the remainder
unsure). The most common negative comment (5 responses) was that students found the messages annoying. However, the most common comment (52 responses) described the convenience in participating with some indicating it was less of a time commitment compared to traditional studies.

Evidence for Validity

First, to determine how generalizable the sample is, participants were compared to the non-participants on each variable describing an incoming characteristic: SAT sub-scores and the Surface Approach and Deep Approach score from the rSPQ. Scores on each metric are compared in Table 12. Using the two one-sided t-tests method (Lewis & Lewis, 2005) for establishing equivalence, with an equivalence interval equal to the small effect size (Cohen’s $d = 0.2$), the two groups were equivalent on Math SAT and the Surface Approach (Cohen, 1988). The departures from equivalence were minor and when the interval was expanded to $d = 0.25$ the two groups were equivalent on all metrics. Participants were also compared to non-participants based on demographic characteristics of gender and minority status. For this comparison the chi-square test was used with the effect size estimated using Cohen’s $w$. The comparison found that both differences were less than a small effect, which Cohen operationalized as $w = 0.10$. For gender $\chi^2 = 3.27, w = 0.06$, and for minority status $\chi^2 = 2.39, w = 0.05$. The above comparisons serve to investigate self-selection bias in this study and found only small departures from the participants and the non-participants on the measures considered. These measures only serve as an indirect measure of self-selection bias as it is still possible that the study habits of the participants and non-participants differ and study habits of non-participants could not be investigated with the data collected. It is therefore proposed that no evidence was found to
believe that the sample is biased by self-selection and the sample may be generalizable to the population of General Chemistry students at the setting.¹

Table 12. Generalizable Validity: Comparing Participants to Non-participants

<table>
<thead>
<tr>
<th></th>
<th>Participants</th>
<th>Non-participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (St. Dev.) N</td>
<td>Average (St. Dev.) N</td>
</tr>
<tr>
<td>SAT Math</td>
<td>554 (65) 237</td>
<td>550 (69) 458</td>
</tr>
<tr>
<td>SAT Verbal</td>
<td>552 (70) 237</td>
<td>545 (74) 458</td>
</tr>
<tr>
<td>Deep Approach</td>
<td>32.7 (6.6) 288</td>
<td>31.8 (6.7) 509</td>
</tr>
<tr>
<td>Surface Approach</td>
<td>23.6 (6.3) 288</td>
<td>23.9 (6.2) 509</td>
</tr>
<tr>
<td>Gender</td>
<td>65% Female (300)</td>
<td>59% Female (594)</td>
</tr>
<tr>
<td>Minority</td>
<td>45% URM (277)</td>
<td>40% URM (559)</td>
</tr>
</tbody>
</table>

¹URM = under-represented minority (as defined by the National Science Foundation)

To explore the content of the responses, the text messages were coded using an open-coding scheme. The coding process resulted in 16 codes as shown in Table 13. Each response was coded and responses could be coded with multiple codes. For example, “Yes the back of book problems, reading the chapter, and doing the online homework assignment” was coded for Textbook, Practice Problems and Homework. To check the inter-rater reliability of the coding scheme, 10% of the text messages were randomly selected and coded by a researcher who was independent of the first coding pass. The resulting codes agreed with the original code for 94% of the responses. Table 13 also presents the relative frequency of the codes as the percent of responses that used a particular code.

¹Analyses presented later in this manuscript will rely on a subset of the sample based on frequencies of responses to text messages. The correlation between frequency of responses and each of the measures in Table 12 were found to be weak, with $r = 0.16$ for response rate to Math SAT or Verbal SAT and $|r| < 0.14$ for the other measures, indicating subsets generally continue with minor departures from the population.
<table>
<thead>
<tr>
<th>Code</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not study</td>
<td>42.2%</td>
</tr>
<tr>
<td>Reviewed notes or PowerPoint</td>
<td>18.8%</td>
</tr>
<tr>
<td>Reviewed the textbook</td>
<td>16.4%</td>
</tr>
<tr>
<td>Online homework</td>
<td>14.2%</td>
</tr>
<tr>
<td>Practiced problems</td>
<td>6.8%</td>
</tr>
<tr>
<td>Previous exams or study guides</td>
<td>5.7%</td>
</tr>
<tr>
<td>Unspecified yes</td>
<td>4.5%</td>
</tr>
<tr>
<td>Used online materials</td>
<td>2.6%</td>
</tr>
<tr>
<td>Worked with friends or in a group</td>
<td>2.4%</td>
</tr>
<tr>
<td>Attended peer leading or reviewed peer leading assignment</td>
<td>2.1%</td>
</tr>
<tr>
<td>Worked with a tutor</td>
<td>1.9%</td>
</tr>
<tr>
<td>Attended class</td>
<td>1.1%</td>
</tr>
<tr>
<td>Made flashcards</td>
<td>0.9%</td>
</tr>
<tr>
<td>Visited professor</td>
<td>0.3%</td>
</tr>
<tr>
<td>Attended lab</td>
<td>0.2%</td>
</tr>
<tr>
<td>Reviewed tables, models or charts</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

Text messages were then also coded dichotomously as either a study habit was used or the participant did not study. The codes unspecified yes, attended class, attended peer leading or attended lab were coded as missing in this categorization as it was not clear whether these participants had employed a study habit. With the new dichotomous codes, the percent of participants employing a study approach was determined for each text message inquiry. The percent of participants using a study habit is plotted by date in Figure 8, using only those participants who responded to at least half of the 28 inquiries (N = 188). The vertical lines in Figure 8 correspond to the exam dates in the class. From Figure 8, the percent of students who report studying increases leading up to each exam, peaks at the exam date and subsequently drops-off. This matches the expected pattern of instructional experience where student inquiries tend to ramp up leading up to the date of an exam, lending content validity to the responses received.
Ultimately, the measure of students’ study habits proposed is still reliant on self-report. Self-reported data may be influenced by factors that cannot be ruled out such as participants’ belief in a socially desirable response pattern or errors in participants’ efforts to recollect. Such factors would impact the accuracy of the responses as a measure of actual student actions. As study habits by definition occur outside of a controlled research setting, attempts to triangulate the measure without relying on self-report would require extensive observations that would impose on participants’ privacy. This serves as an unavoidable limitation of this study though it is proposed that participants’ self-report of study habits do offer value in understanding the factors needed for successful academic performance.

**Figure 8.** Percent of Responses Describing a Study Habit

**Relationship of Study Habits to Academic Performance**

Identifying successful study habits can guide efforts to improve study habits through student advising. The knowledge of productive study habits can also inform evaluations of reform pedagogies allowing an exploration of the extent reform pedagogies promote effective study
habits. To investigate the relationship of study habits to academic performance, each participant was characterized by the percent of the participant’s responses that indicated each of the study habits shown in Table 13. Second, only participants who responded to half of the text message inquiries were considered to promote stability in the percentage. That is, a participant who indicated reviewing notes in 14 out of 21 responses indicates a more stable pattern than another participant who indicated so in 2 out of 3 responses. Finally, academic performance was operationalized by performance on the cumulative final exam discussed earlier. This measure was chosen as the clusters represent study habits across the semester and the final exam was the only measure to occur at the end of the semester.

Initially, correlations between each study habit and the final exam were conducted. Each correlation indicated a weak relationship with the strongest relationship of 0.14 between percent of responses using the textbook and final exam score. Since correlations only indicate the strength of a linear relationship, the data was further explored for the possibility of relationships that do not follow a linear pattern. Owing to the substantial number of study habits present, the decision was made to conduct a cluster analysis to look for patterns among the multiple study habits. Cluster analysis is an algorithm that measures the distance between each case (student) on the variables (frequency of study habits) and combines pairs of students who feature the smallest distance into a cluster. The algorithm continues to combine students and clusters of students until it reaches a user-specified number of clusters. In this way, cluster analysis can be used to find groups of students who have similar profiles across multiple variables (Everitt et al., 2011). Cluster analysis can be used to describe the data in terms of number of students per group and the average study habits within each group. These groupings can then facilitate investigating relationships among other measures.
For the cluster analysis, only the six most prevalent study habits in Table 13 were used, as these were each represented by at least 5% and were also readily interpretable (the next most prevalent code would be the unspecified yes). A hierarchical cluster analysis using Ward’s method and squared Euclidean distance was employed to create clusters that were distinct from each other (Aldenderfer and Blashfield, 1984). To determine the number of clusters, the cluster analysis began with six clusters that were evaluated based on sample size in each cluster and the average percent for each study habit. Then an analysis to create five clusters was conducted to determine which two clusters were combined; these clusters were evaluated based on qualitative similarity on study habit percentages and the relative sample size of each cluster. The analysis was continued until reducing the number of clusters meant losing a cluster that was substantially distinct. The intent was to determine the number of clusters that led to reasonable representation in the sample for each cluster and where each cluster was distinct. This resulted in three clusters that are characterized in Table 14.

<table>
<thead>
<tr>
<th>Study Habits</th>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Size</td>
<td>64</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Did not study</td>
<td>67% (13%)</td>
<td>26% (14%)</td>
<td>33% (15%)</td>
</tr>
<tr>
<td>Reviewed notes or PowerPoint</td>
<td>8% (9%)</td>
<td>22% (22%)</td>
<td>26% (16%)</td>
</tr>
<tr>
<td>Reviewed the textbook</td>
<td>8% (11%)</td>
<td>35% (16%)</td>
<td>8% (8%)</td>
</tr>
<tr>
<td>Online homework</td>
<td>5% (7%)</td>
<td>11% (9%)</td>
<td>25% (16%)</td>
</tr>
<tr>
<td>Practiced problems</td>
<td>4% (6%)</td>
<td>10% (12%)</td>
<td>6% (9%)</td>
</tr>
<tr>
<td>Practice tests or study guides</td>
<td>3% (4%)</td>
<td>6% (7%)</td>
<td>9% (8%)</td>
</tr>
</tbody>
</table>

**Bold** indicates study habit has more than +0.5 standard deviation different than the overall average; **italic underline** indicates study habit is less than -0.5 standard deviations different than the overall average.
Table 14 describes three distinct clusters that arose from the study habits in the sample. To place the values in context, 14% would indicate that they used the study habit at least twice and at most four times over the course of the semester. The sample distribution among the three clusters is relatively even which suggests that each cluster has prevalence among the sample. Participants in Cluster 1 indicated not studying far more often than the rest of the sub-sample (67% versus 42% for the sub-sample) and subsequently indicated reviewing notes and the online homework less often than the sub-sample. Cluster 2 was more than one standard deviation greater than sub-sample on use of the textbook (35% versus 16%). Cluster 2 was also higher on practicing problems and lower on the percentage of not studying. Cluster 3 was noteworthy for describing the online homework as their study habit, but was also higher on reviewing notes and the practice tests.

The three clusters were compared on the five other measures with data presented in Table 15. To compare the clusters an Analysis of Variance (ANOVA) was performed with \( \alpha = 0.05 \) which provides a group-wise error rate of 0.23 across the five tests. The effect size was also characterized by Cohen’s \( f \), where 0.10 is a small effect and 0.25 is a medium effect (Cohen, 1988). Interestingly, neither SAT sub-score was found to be statistically significant with negligible effects for Verbal SAT (\( F = 0.233; p =0.792; f = 0.06 \)) and Math SAT (\( F = 0.135; p = 0.874; f = 0.04 \)). For the study approaches, the clusters differed with medium effects on both the deep approach (\( F = 4.190; p = 0.017; f = 0.22 \)) and the surface approach (\( F = 7.315; p < 0.001; f = 0.27 \)). Post-hoc comparisons using the Tukey test indicate that the significant difference is Cluster 1 is higher on the surface approach than the other two clusters and Cluster 2 is higher on the deep approach than Cluster 1. On the final exam metric, the clusters were also different with a near medium effect (\( F = 3.663; p = 0.028; f = 0.21 \)). Post-hoc analysis describes the significant
difference as Cluster 2 higher than Cluster 1. An ANCOVA analysis controlling for SAT sub-scores on the final exam measure indicated similar results \( (F = 3.881; f = 0.24) \) as the original ANOVA analysis.

**Table 15. Study Habit Clusters Compared**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAT Math</td>
<td>566 (62)</td>
<td>561 (71)</td>
<td>560 (57)</td>
</tr>
<tr>
<td>SAT Verbal</td>
<td>557 (70)</td>
<td>566 (81)</td>
<td>558 (71)</td>
</tr>
<tr>
<td>Deep Approach</td>
<td>30.4 (6.5)</td>
<td>33.7 (6.4)</td>
<td>31.8 (5.8)</td>
</tr>
<tr>
<td>Surface Approach</td>
<td>25.7 (5.9)</td>
<td>22.1 (6.1)</td>
<td>22.4 (5.6)</td>
</tr>
<tr>
<td>Final Exam</td>
<td>43.8 (13.3)</td>
<td>51.1 (15.2)</td>
<td>46.8 (14.0)</td>
</tr>
</tbody>
</table>

Thus, it appears that Cluster 2, which comprises roughly one-third of the sample, had higher scores on average on the final exam measure. This suggests the study approaches described as reviewing the textbook and practicing problems leads to increased academic performance in the course. Not surprisingly, Cluster 1, which indicated predominately not studying, performed worse. That Cluster 2 scored higher on the deep approach and Cluster 1 on the surface approach lends external validity to the qualitative difference between these two groups. Cluster 3’s performance on the final exam is interesting as it was comparable to Cluster 1. The study efforts of Cluster 3 are more concentrated on the online homework. It is hypothesized that these students perceived the completion of the required online homework as suitable preparation for the exams. The central feature of the hypothesis is the emphasis on perception. Since the online homework was a mandatory part of the class it is likely that the strong majority of students completed it, however the students in Cluster 3 may have perceived it as satisfactory preparation whereas students in Cluster 2 believed that additional preparation was necessary. Thus, Cluster 1 may be described as knowingly not studying, Cluster 3 as believing the required course components
constitute satisfactory studying and Cluster 2 studied in addition to the required course components by relying on the textbook and practicing problems.

The relationship of the study habits measured by ESM to a measure of academic performance serves as support for external validity of the data collected. The finding that students who study more regularly perform better on the cumulative final exam may not be surprising. However, the findings that approximately one-third of the sample study regularly, which matches the baseline observed in Figure 8, is of importance as it suggests that there is ample ground for promoting effective study habits. That the students who study regularly are also not distinguishable from the other groups based on SAT scores also partially rules out the competing explanation that these students were more academically prepared prior to the semester. Another possible explanation for differences in academic performance may include differences between clusters in student motivation to succeed in the course; in particular, it is plausible that differences in motivation may manifest themselves in more frequent studying.

**Study Habits Change over the Semester**

To investigate changes in study habits over the course of the semester, the analysis focused on the text message inquiries that were sent out immediately preceding each exam. The decision to focus on these four text message inquiries was based on the increase observed in describable study habits that coincided with the exams as shown in Figure 8. It will also lend the most insight into students’ exam preparation strategies. As a measure of change in study habits over the semester, the analysis was conducted on only the 113 participants who responded to each of the four messages in question; otherwise, observed changes could result from trends in missing data. A separate lexical analysis was conducted on the responses from each of the four text message
inquiries. Lexical analysis is an algorithm designed to automatically categorize written responses. The lexical analyses were conducted using SPSS Text Analytics (IBM, 2011). This program used linguistics-based text analysis, which combines phrases into a common category if the differences between phrases are the use of synonyms (e.g. practicing problems and doing problems). Some of the resulting categories were then manually combined such as practice tests and old tests. Lexical analysis also facilitates an investigation into patterns of overlap among categories that provides insight into the extent that study habits are diversified at each time point.

The end result created 18 categories from the responses across the set of four inquiries. Note these categories were created independently of the codes described in Table 13. A sizable advantage of the lexical analysis technique is the ability to demonstrate the categories and interrelations between each category in a web diagram. Web diagrams were created for each exam (Figures 9 through 12) focusing only on categories with at least five responses. The web diagram represents each category with a node, and the size of the node is proportional to the frequency of the category. The frequency of each category is indicated in parenthesis inside each node. Nodes are connected with lines that indicate the extent the connected categories were mentioned together in a response. The type of line indicates the extent the categories are shared as a proportion of the smaller node. A solid line indicates that 60% or more of the responses that were categorized by the smaller node were also present in the category in the larger node. A long dash line indicates 40% to 59% agreement, a square dotted line indicates 20% to 39% agreement and no line indicates below 20% agreement. Reviewing the web diagrams can provide insight into changes in study patterns that occurred throughout the term. For context in interpreting trends in the web diagrams, the relevant topics from each exam are shown in Table 16.
Table 16. Content on Exams

<table>
<thead>
<tr>
<th>Exam</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam 1</td>
<td>Properties of light, electron configurations, periodic trends</td>
</tr>
<tr>
<td>Exam 2</td>
<td>Lewis structures, molecular shapes, polarity</td>
</tr>
<tr>
<td>Exam 3</td>
<td>Gas laws, thermodynamics</td>
</tr>
<tr>
<td>Final Exam</td>
<td>Intermolecular forces, colligative properties, cumulative exam included prior content</td>
</tr>
</tbody>
</table>

In the Exam 1 (Figure 9) diagram, notes, previous tests, textbook and homework are the most prominent, with PowerPoint (PPT) slides also mentioned. The links show moderate overlap among these five categories, though notably no significant overlap was found between previous tests and PowerPoint or previous tests and textbook. In the Exam 2 (Figure 10) diagram the study pattern is more concentrated on notes, previous tests and textbook with moderate overlap among almost all of the categories. In Exam 3 (Figure 11) the textbook is reduced in prominence and the studying was more focused on previous tests; also the relations among nodes are generally weaker than in Exam 2 indicating less reliance on multiple study approaches. In preparing for the cumulative Final Exam (Figure 12) the use of the textbook has returned to prominence along with notes and previous tests, similar to Exam 2. This diagram is also the most interconnected web suggesting a stronger reliance on multiple studying techniques, possibly owing to the cumulative nature of this exam.

Looking for changes across study patterns, one clear trend is the diminished role of studying homework in preparation for the exams. In Exam 1, homework was among the most prominent nodes, whereas in each subsequent exam it is a minor node. This may describe students’ perceiving a lack of relevance of the homework assignments in exam preparation after the first exam. For context, the online homework was always due one to two days before each of these four text message inquiries so that it was likely students were working on the assignments in the time frame indicated. Students could also review the homework assignments after the due
date. Incidentally, after the semester had completed, the instructors at the setting discussed deliberately including one or two questions modified from the homework assignment in each of the exams to emphasize to students the importance of understanding the process of problem solving in the homework over simply arriving at the correct answer. By making this change it is possible that students may benefit more from engaging in the homework which would be reflected in their study habits and related to their academic performance.
Another trend among the web diagrams is the diminished role of the textbook and notes in the Exam 3 diagram. Exam 3 strongly relied on math content (see Table 15) differing from the preceding exams. Students may respond to this by studying the textbook and notes less and focusing more on the instructor provided materials in the PowerPoint slides and previous tests. Other explanations are also possible such as time constraints related to other courses giving exams,
the perceived challenge of the practice tests that were posted taking up more student time or students finding the textbook less helpful in this content.

Returning to the research question, there appears to be considerable evidence of changing study habits among a common group of students over the course of the semester. The changing role of homework, textbook, notes and the use of multiple study techniques suggest that student study habits differ across the exams. The changes may be for many reasons including students responding to the perceived effectiveness of study techniques for each exam, the perceived nature of the content on each exam or the quality of study materials available, or competing interests for students’ time. The changes in the nature of links also indicates that the variety of techniques used by students changes over the course of the semester and are amplified when taking a final exam, possibly as a result of the cumulative nature of the exam.

Conclusions and Future Work

This study has shown the feasibility of using text messages to provide considerable data on students’ self-reported study habits in General Chemistry. Among the principle limiting factors is recruiting students to participate, which may become an issue depending on the intended use. Future work may benefit by modifying the incentive structure for recruiting students. Second, there is evidence for validity of the text messages in that the response pattern matches the expected trend relative to the exam dates in the setting. Additionally, the recruited sample featured minor departures from the overall population on incoming metrics, including a measure of study approaches, lending support to the consideration that the results are generalizable to the population of General Chemistry students at the setting.
Next, the study provided evidence that study habits are related to academic performance in the course, notably by students using study habits that are in addition to the mandated course requirements. In this study, use of the textbook was most prominent as the additional study habit. A direct instructional implication that results from this study is the potential benefit of discussing with students the need to study beyond mandatory course components. In the current study one-third of the students described mandatory course components as their principal means for studying and these students performed comparably to students who did not report studying. Future research could have instructors discuss with students the results shown here to students and measure the impact on student study habits or academic performance.

One of the most interesting areas of future work may be an investigation on the impact of instructional techniques to impact study habits. Indeed one of the more surprising outcomes of this study was the infrequent mention of group work or studying with friends (Table 13) as it seemed possible that the weekly group work during the peer-led meetings would facilitate greater use of study groups outside of class. To investigate this area further, the impact of incorporating reform pedagogy or training sessions on how to study can be investigated in either a repeated measures or quasi-experimental design using text messages to measure students’ study habits. Such a study may inform causal mechanisms behind evidence-based instructional practices. For example proponents of cooperative learning have indicated social constructivism as a potential explanation for improved learning outcomes that have been observed (Mutyhyala and Wei, 2013). The causal mechanism for learning would be that students’ social processes within group-work have facilitated their conceptual understanding. An alternative causal mechanism however is that students engaged in cooperative learning may become dissatisfied with their own progress in comparison to their peers and as a result study more. The plausibility of the alternative
explanation is supported by the time available outside of class relative to in class and the observed academic benefits of study habits herein. An investigation into the impact of evidence-based instructional practices on study habits can then support or dissuade the alternative explanation proposed.

This study has also shown that students’ study habits can change over the course of the semester. This finding has relevance for work that relies on a single measure of particular study habits (as opposed to more general study approaches) extrapolated to describe students’ habits throughout the term. It also provides some support to the expectation that instructor actions can influence student study habits. Relating changes in study habits to measures of reflective action (e.g. metacognition) or interviewing students regarding their study actions prior to each test may offer additional support for this contention. Additionally future research that investigates how changes in study habits relate to academic performance is warranted, as whether consistent or adaptable study habits are more beneficial remains an open question.

Finally, ESM has the flexibility to potentially support a diverse range of instructional strategies. For example, the action of messaging students outside of class can, by itself, serve as an instructional intervention. Instructors can use text messages to direct students toward online resources, set-up peer study groups or remind students of deadlines in a timely fashion. Additionally, the messages can be tailored for individual students or small groups; for example messages can notify a group of students who haven’t completed an online homework assignment of an upcoming due date or inform a student who has struggled that the student’s recent test score shows an improvement over past performance. Early research in a wide range of educational settings has shown that such tailored messages have a strong potential for producing positive gains (Dynarski, 2015). This approach may offer a non-intrusive way to show faculty concern for
student performance which, when missing, has been cited as a factor in student attrition from the
STEM disciplines, particularly among minority students (Tsui, 2007; Museus et al., 2011).

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CHAPTER VI:
CAN THEY SUCCEED? EXPLORING AT-RISK STUDENTS’ STUDY HABITS IN COLLEGE GENERAL CHEMISTRY

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Introduction

Students who perform poorly in courses are a primary concern for education researchers and instructors. High attrition rates of 30% or more in STEM gateway courses during the initial years of college have been reported in different institutions throughout the country (Harris et al., 2004, Gabriel, 2008, Griff & Matter, 2008, Benford & Gess-Newsome, 2015, Gultice et al., 2015). General Chemistry is one of those initial courses that are generally perceived by college students as difficult (Tai et al., 2005). Failure rates of 50% and more in general chemistry courses have been reported by certain institutions (Chambers & Black, 2008, Gafney, 2008). High failure rates in general chemistry delay or prevent students from entering advanced courses in the course sequence since General Chemistry is required for most STEM majors. High failure rates may also cause decreasing confidence and morale for students and increasing costs for students and universities. At many institutions, without demonstrating satisfactory understanding of general
chemistry knowledge, students cannot continue pursuit of any STEM fields. To aid in the improvement of student retention in General Chemistry, research literature has identified multiple student characteristics that relate to a higher likelihood of not succeeding in General Chemistry. Students who exhibit these characteristics are referred to as “at-risk”. This investigation seeks to better understand the actions and experiences of at-risk students with the intent that doing so will offer potential paths toward improving student retention in General Chemistry.

**Identifying at-risk students**

Prior research regarding identification of at-risk students in chemistry has been generally focused on two main student characteristics. A major component of research has been focusing on exploring cognitive characteristics of students, including standardized tests such as the SAT (e.g., Pickering, 1975, Spencer, 1996, Lewis & Lewis, 2007, Cracolice & Busby, 2015) and ACT (Carmichael et al., 1986), prior knowledge (Hailikari & Nevgi, 2010), high school GPAs (Carmichael et al., 1986) and diagnostic tests (Russell, 1994) as predictors to identify at-risk students. The second category of studies considers students’ affective characteristics, for example, self-efficacy (House, 1995), attitude (Xu et al., 2012, Cracolice & Busby, 2015) and self-concept (Lewis et al., 2009, Chan & Bauer, 2014). Recent research provides evidence that the cognitive and affective characteristics describe unique factors in understanding chemistry performance (Xu & Villafane, 2013, Lewis et al., 2009). In addition to the two main student characteristics, other predictors such as demographic information (Wagner et al., 2002, Tai et al., 2005), personality characteristics (House, 1995) and student metacognitive skills like self-evaluation (Potgieter, 2010) have also been reported in research articles.
Among those predictors, there is a long history of using SAT math score to predict students’ academic performance in chemistry courses in the literature. SAT math is a component of the SAT, a standardized college-entrance test commonly administered in secondary school. SAT math is designed to measure quantitative reasoning including problem solving, modeling and algebraic structure (College Board, 2016). SAT math was strongly associated with student academic performance in chemistry; students who have low SAT math scores are more likely to have low academic performance in chemistry courses (e.g., Pickering, 1975, Nordstrom, 1990, Spencer, 1996, Lewis & Lewis, 2007). The cut-off scores of SAT math used to determine at-risk students in chemistry were varied due to the diverse incoming abilities of students among universities. Lewis & Lewis (2007) examined a range of SAT math cut-offs and found that the bottom 25% to 35% of the sample by SAT math made approximately 65% to 75% correct predictions in describing a student as at-risk. Combined the research to date indicates that students who enter General Chemistry with low SAT math are disproportionately likely to not succeed in the course.

**Helping at-risk students**

Past research reported utilizing various methods to help at-risk students. Valentine *et al.* (2011) conducted a meta-analysis of past work on the effects of college retention programs aimed at helping at-risk students in higher education. In the meta-analysis, they defined at-risk students as academically underprepared and economically disadvantaged students; they found inconsistent effects sizes among 18 studies. The average effect size of these retention programs on at-risk students’ various academic achievement outcomes (mainly GPA) was 0.07 and the range was from -0.61 to 0.93. The meta-analysis indicated that more comprehensive interventions led to more effective results. For example, an intervention that implemented a seminar designed to assist
college adjustment, in conjunction with smaller classes and other activities like tutoring led to more positive effects on attendees (Hecker, 1995) than the smaller scale intervention that added a journal-writing component to an English composition class (Cohen Goodman, 1998).

In chemistry, the main practices that help improve at-risk students’ success in chemistry have been reported as offering external remedial coursework (Mechstroth 1974, Pickering 1975, Walmsley 1977, Bentley & Gellene 2005, Heredia et al., 2012), group activities (Mason & Verdel, 2011) or training programs for at-risk students (Shields et al., 2012, Hall et al., 2014). Remedial courses typically offer at-risk students lectures on preparatory chemistry content concurrently or consecutively with the regular lectures. Pickering (1975) reported providing a supplementary course for students who had SAT math scores of 610 or lower. This course taught students the solutions of diverse types of problems associated with the content students learned in the parallel chemistry lecture course. Results showed that students who attended the supplementary course had mean grades that were 0.29 (on a 4-point scale) higher than the comparable students who did not attend, and the difference was significant. Interestingly, Bentley & Gellene’s (2005) study suggested that the effect of a remedial course depended upon students’ SAT math scores. They offered multiple sections of an Introductory Chemistry course that aimed to teach vocabulary, concepts and problem solving skills for students scoring below 50% on chemistry placement test (CPT). Results showed that students with low scores on the CPT who took the Introductory Chemistry course finished with a grade in General Chemistry that was ¼ to ½ of a letter grade higher than their counterparts who did not take Introductory Chemistry. However this effect was only found for students with SAT math scores from 460 to 600, little or no effect was found for students below or above this range. The above studies focus on providing more repetition of course content for at-risk students. Similar to the general results suggested by the meta-analysis
study, these articles report mixed effectiveness of these practices for at-risk students in chemistry. Even though positive effectiveness has been reported, since the above studies all used student grades as the outcome measures, the effectiveness could be partially attributable to how instructors assigned grades to students.

Other past work describes efforts to improve at-risk students’ study skills through training programs or group activities. Hall and colleagues (2014) trained less prepared students who were in the bottom quartile of SAT math scores or lacked advanced placement (AP) courses in math and science by using a project called Science Advancement through Group Engagement (SAGE). SAGE was run concurrently with the regular lectures and implemented study group sessions focused on foundational chemistry knowledge with the aid of teaching assistants. SAGE also trained students with a self-regulated learning (SRL) approach. SRL encourages students to follow a study cycle of task analyses, planning, reflection and self-adjustment based on the value and meaning of their efforts. The results showed that the retention of SAGE participants was more than double that of the non-SAGE participants and historical group in chemistry sequence courses. By the fourth course, Organic Chemistry II, SAGE participants performed as well on final course grades as those students who had stronger high school backgrounds with more AP science and math courses and significantly higher SAT scores. Shields and colleagues (2012) implemented a transition program including extended-length recitations, peer-led team-learning (PLTL) study groups and peer-mentoring groups to help underprepared students who were in the bottom 25% of predicted scores based on ACT math, total of STEM AP test scores and online diagnostic scores. The study found the transition program helped the participants make significant gains in final general chemistry course scores that combined quiz scores, midterm and final exams in comparison to students who were in regular recitations only.
In both Hall, *et al.* (2014) and Shields, *et al.* (2012), at-risk students were trained with certain study skills or strategies and notable academic benefits were observed. However, neither of these investigations incorporated a measure of study habits so it is not possible to make a definitive claim that the interventions employed influenced student study habits. Another plausible explanation might be self-selection bias where participating students possessed higher motivation to succeed than the reference group from the onset of the study. Additionally, it has not been well established that the reason at-risk students struggle in General Chemistry is related to their study habits. That said, the notable benefits observed are cause for further investigation into the relationship between study habits and the academic success for at-risk students.

**Effective study habits**

**Theoretical Framework**

The theoretical framework used in this investigation for describing the quality of participants’ study habits was Sinapuelas and Stacy’s *Learning Approaches Framework for Chemistry* (2015). This framework is built on an extensive body of research that describes learning approaches as surface or deep (Marton & Salijo, 1976, 1984, John Biggs, 1987a, 1987b). Surface level learners tend to rely on techniques such as rote memorization of unconnected facts, reading and rereading resources provided by instructors, and relying on others for help when they experience difficulty with homework or other assignments. In contrast, deep level learners utilize techniques such as making connections between pieces of information based on overarching concepts, constructing their own supplemental content such as study guides or practice problems, and working through difficult problems collaboratively with peers. Additionally, surface learners
tend to be extrinsically motivated by factors such as grades, whereas deep learners are intrinsically motivated to learn material for the satisfaction of gaining understanding and developing personal knowledge.

Sinapuelas and Stacy (2015) built on this model in an effort to characterize the study approaches of introductory, non-major college chemistry students. In this study, 61 students were interviewed at three time points throughout the semester. In the interview students were asked to describe the resources they used to prepare for exams and to elaborate on how they were used. The analysis of student responses led to the creation of the Learning Approaches for Chemistry framework that describes learning approaches in four hierarchical levels:

Level 1: Gathering Facts – Students tend to memorize unrelated facts by scanning course materials, typically independently. Students do not monitor their own learning.

Level 2: Learning Procedures – Students begin to make connections between pieces of information and try to work out practice problems. Students rely on others for answers, but they possess basic metacognitive skills such as assessing for procedural errors.

Level 3: Confirming Understanding – Students evaluate and question data, form their own arguments, and work collaboratively with peers. Students assess their own knowledge based on their ability to justify and explain answers.

Level 4: Applying Ideas – Students question data, try to use concepts to explain real-world phenomena, and act as “teachers” with their peers. Students possess advanced metacognitive skills such as assessing for gaps in conceptual understanding.

Levels 1 and 2 emphasize memorization, matching the description of surface level approaches; levels 3 and 4 emphasize content generation and application, matching the deep level approaches (Sinapuelas and Stacy 2015). Since this framework provides additional description to
the surface-deep dichotomy and describes students’ approaches while engaging in studying chemistry, this framework will be used to describe the quality of students’ study habits in this work.

The Role of Study Habits

Research studies have demonstrated an association between study habits and academic performance in different settings. Crede and Kuncel (2008) published a meta-analysis study and reported that the average correlations for study habits (measured by various study skill inventories) and college GPA in different disciplines was 0.33 with a range of 0.09 to 0.51. Additionally, the meta-analysis also found the relationships between study habits and cognitive ability measures like college admissions tests (e.g. SAT and ACT) were trivial, indicating study habits are independent of these cognitive ability measures. This result also suggested that it is possible that students can benefit from effective study habits regardless of their incoming ability.

Specific to General Chemistry, Chan and Bauer (2016) divided students into high, medium and low affective groups using cluster analysis on the results of a survey measuring attitude, self-concept and motivation in chemistry. Surveys, open-ended questions and interviews were used to investigate students’ study strategies used in the lecture and when preparing for exams. Students in the high group reported understanding the notes they took in the lecture more frequently than the low group, and the low group relied more on others for help when preparing for exams, analogous to the surface level learning description in Sinapuela and Stacy’ article (2015). In addition, answers to the open-ended questions showed that the high group tended to be more confident about their study strategies while students in the low group felt less confident about their strategies and planned on changing their current study strategies, suggesting that confidence and studying
strategies are related constructs.

Ye et al. (2015) examined students’ study habits of General Chemistry students outside the class via inquiries sent through text messages. Students were characterized based on the types and frequencies of studying reported in their text message responses. Using cluster analysis, three patterns of studying emerged: students who knowingly do not study (Cluster 1), students who study in addition to the mandatory course components such as reading the textbook or practicing problems (Cluster 2) and students who primarily describe mandatory course components such as doing homework assignments as studying (Cluster 3). These three groups were compared on the measures of final exam and revised two-factor Study Process Questionnaire (rSPQ) (Briggs, 2001), an instrument used to measure students’ study process with two sub-scales of deep and surface approaches. The results of ANOVAs showed that students in Cluster 2 were significantly higher on the final exam than the other two clusters. Students in Cluster 1 were significantly higher on the surface approach than the other two clusters, and Cluster 2 was significantly higher on the deep approach compared to Cluster 1. These results indicate that frequency of studying relates to academic performance in General Chemistry though the sample was not delineated for at-risk students. In reviewing the literature, no research exploring the role of at-risk students’ study habits in the context of post-secondary chemistry was identified.

**Purpose of the study**

The broad intent of this study is to better understand the frequency and quality of studying (herein referred to as study habits) of at-risk students as the habits relate to academic performance in General Chemistry. Improving our understanding of the role of study habits potentially offers a primary path toward improving student success in General Chemistry. Past research has shown
that the quality and frequency of studying plays a role in student success when examined for a representative sample of students in General Chemistry (Sinapuela and Stacy 2015, Li et al., 2015). However, it is not known whether these relationships hold true for at-risk students, thus it is not known whether the study habits of at-risk students can explain the lower success observed for at-risk students; that is, whether at-risk students have appreciably different study habits than the rest of the population and whether this difference is responsible for the observed lower success rates. Accordingly, this research study has the goal to explore the study habits of at-risk students and their relationship to student success as well as to initiate an exploration into the characteristics of at-risk students who succeed well beyond their predicted performance. This research is guided by the following research questions:

1. What is the relationship between study habits (frequency) and academic performance in college General Chemistry for at-risk students as compared to the larger remaining General Chemistry cohort?

2. What are the effective and non-effective study habits (frequency and quality) of at-risk students in college General Chemistry and what additional factors may explain the study habits employed?

**Methods**

**Research setting**

This study was conducted at a large public research university in the southeastern United States. At the setting, there were four General Chemistry I classes. The class size of each class was between 200 and 240 students. The classes were coordinated, using a common textbook, syllabus
and grading scheme. All classes used an online homework system and gave common tests at the same time. Students attended the regular lectures twice a week and problem-solving peer leading sessions (Gosser et al. 2006, Lewis, 2011) once a week. The textbook used for the classes was “Chemistry: A Molecular Approach” (Tro, 2013). Eight online homework assignments were assigned throughout the semester using the Sapling Learning online homework system. Tests consisted of three in-class midterm tests (15% each of their grades) and a cumulative final test (25%). The format of the tests consisted of multiple-choice questions developed by the instructors and a series of true/false questions. These true/false questions called Measure of Linked Concepts (MLCs), were developed by the researchers in this study. MLCs are an instrument used to promote students making connections within the course. For an MLC, students were provided a prompt that describes a chemistry situation such as “an aqueous solution of 0.1M NH₄Cl”. Students were then asked to determine the validity of a series of statements related to the prompt. The statements were deliberately planned to cover both recent content coverage and previous content in the course to emphasize the links across topics in the course (Ye et al., 2015). Past tests were posted before each test for review purposes through an online course management system. In addition to the four tests, grades were also determined by three effort-based measures (10% each) including performance on in-class clicker questions used in the regular lecture setting, attendance and participation in peer leading sessions and the online homework assignments.

**Data collection**

The study utilized Experience Sampling Methodology (ESM), a research method that asks participants to self-report their actions or psychological state in their natural environment at certain times (Hektner, 2007). In ESM participants’ experiences in the moment are recorded at multiple
instances with the aid of technology. ESM has been described as systemic phenomenography as it focuses on participants’ self-report of a construct, which can be either psychological states or actions that a participant observes or participates in. The strength of ESM is the systemic collection regarding a construct, which facilitates the exploration of patterns over time and can aid in establishing reliability of the responses. By measuring multiple times, ESM also has the advantage that it can rely on a much more proximal retrospective recollection as opposed to a singular measurement in the same time frame. In this study, ESM was used to assess students’ study habits outside the General Chemistry I classroom via text messages.

The data collection spanned two semesters. First, in the spring semester, students were recruited from three of the four General Chemistry I classes on the first day of class. In the recruitment, the nature of the study was described to students. The participants would be asked to provide their cell phone numbers and would twice weekly receive a text message that asked the same question: “Have you studied for General Chemistry I in the past 48 hours? If so, how did you study?” The text messages would be sent at random times between 9 AM and 9 PM. Participants would be asked to reply to the message within 12 hours if possible. To encourage participation, students who replied to at least 80% of the text message inquiries would be entered into a raffle for a $25 gift card at the end of the semester. The recruitment led to 301 students agreeing to participate in the study. The text message inquiry was sent out 28 times over the course of the semester. The text message responses from participants were collected and managed via a commercial online website. Student performance such as test scores, course grades, attendance and homework completion, along with demographics and SAT scores were collected from either university records or in-class records. Clickers were used for each class to record student attendance in the setting.
During the following fall semester, 28 at-risk students who replied to at least one quarter of the 28 text message inquiries and were currently enrolled in General Chemistry II were invited via E-mail for a follow-up interview. Students who volunteered would be compensated with a $20 gift card. Six students volunteered and each was interviewed individually. The interviews covered three major themes: students backgrounds, e.g., major and prior chemistry coursework; elaboration on the study approaches reported through text messages, such as how the textbook was used; and questions that were related to students’ approaches to learning, e.g., working with others, metacognition and affective factors. A complete list of interview questions can be found in the Appendix H. The interviews adopted a semi-structured approach. The lengths of the interviews ranged from 20 to 40 minutes. All data collection was carried out with the approval of the university’s Institutional Review Board (IRB).

**Procedures of identifying at-risk students**

SAT math scores were used to determine at-risk students in this study based on established literature. Students were divided into two groups based on their SAT math score: those who were in the bottom quartile (SAT math < 515) in the sample were considered as at-risk students. The remaining cohort with higher SAT math will be referred to as non-at-risk students. To validate whether the method we used to classify at-risk students and non-at-risk students was appropriate, we compared the differences in academic performance in the course between the two groups. Table 17 lists the descriptive statistics for at-risk and non-at-risk students in the General Chemistry I course. Missing data in Table 17 was removed list-wise. As listed in Table 17, the at-risk students’ average score on each test was lower than non-at-risk students with differences ranging from 6% to 12%. Class attendance and homework completion were comparable for the two
groups. In addition, the average course GPA for at-risk and non-at-risk students were 2.41 and 2.78 respectively. The difference in GPA of 0.37 represents just over a partial letter course grade (0.33), such as the difference between C+ and B-. Analysis of course grade distributions show that at-risk students had 9% and 16% lower percentages of students earning grades of A and B, respectively. At-risk students also had a 20% higher percentage earning a grade of C. The course failure rates, which includes students who received a C- or lower in the course and therefore did not meet the minimum requirement to enter the next course in the sequence, was 10.5% for the at-risk students and was 5.8% for the non-at-risk students.

To determine whether the group differences were significant, MANOVA analysis and univariate follow-up tests were conducted on the variables of each test, attendance, homework and course GPA listed in Table 17. Results of the MANOVA showed the group difference in means on the set of outcome variables was statistically significant with $\alpha = 0.05$, $F (7, 529) = 10.243$, $p < .001$, $\Lambda = 0.881$, which means the proportion of variance in the combination of outcome variables that was accounted for by the grouping variable was 12%. The size of the multivariate effect was estimated to be medium ($\omega^2 = 0.10$). The results of univariate follow-up tests revealed statistically significant group differences for each test and course GPA but not attendance and homework completion. Effect size measured by Cohen’s d for comparisons on each individual variable are also listed in Table 17.

In sum, at-risk students performed worse on each single test and final course grade than non-at-risk student in the General Chemistry I course, but the effort measures such as attendance and homework completion were comparable. At-risk students were displaying as much effort as non-at-risk students but achieving less on the tests. These results support the method of identifying at-risk students based on SAT math as appropriate.
Table 17. Descriptive statistics of at-risk and non-at-risk students

<table>
<thead>
<tr>
<th>Variables</th>
<th>Non-at-risk</th>
<th>At-risk</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>384</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>SAT math (Mean ± SD)</td>
<td>583 ± 52</td>
<td>476 ± 39</td>
<td>2.32</td>
</tr>
<tr>
<td>Test 1 (%)</td>
<td>71.2 ± 14.0</td>
<td>63.7 ± 14.1</td>
<td>0.53</td>
</tr>
<tr>
<td>Test 2 (%)</td>
<td>69.9 ± 15.9</td>
<td>63.1 ± 14.9</td>
<td>0.44</td>
</tr>
<tr>
<td>Test 3 (%)</td>
<td>52.8 ± 15.2</td>
<td>41.2 ± 14.1</td>
<td>0.79</td>
</tr>
<tr>
<td>Final Test (%)</td>
<td>51.2 ± 15.2</td>
<td>44.8 ± 16.3</td>
<td>0.41</td>
</tr>
<tr>
<td>Attendance (%)</td>
<td>82.3 ± 19.4</td>
<td>81.0 ± 20.3</td>
<td>0.07</td>
</tr>
<tr>
<td>HW (%)</td>
<td>94.2 ± 14.9</td>
<td>95.8 ± 11.8</td>
<td>0.12</td>
</tr>
<tr>
<td>Course GPA</td>
<td>2.78 ± 0.76</td>
<td>2.41 ± 0.75</td>
<td>0.49</td>
</tr>
</tbody>
</table>

*Cohen’s d = 0.2 (small), 0.5 (medium) and 0.8 (large)*

Data analysis

Text messages were coded using an open-coding scheme. The open-coding scheme resulted in 16 categorical codes, representing the types of the study habits employed by students, for example, “Reviewed notes” or “Practiced problems”. Each text message response could receive multiple codes if multiple study habits were described. Each text response was also coded using dichotomous codes as either a study habit was used or not. With the dichotomous codes, the study percent outside the course was calculated for each student by the number of times the student reported studying divided by the number of responses. Ambiguous codes, for example “attended class,” were coded as missing as it didn’t fit the definition of study habits in this study.

Also, the code “do homework” was coded as missing because homework assignment were mandatory and the data suggests that nearly all students (over 90%) regularly completed the homework regardless of whether they reported it in their response. In the subsequent interviews, students’ discussions of the ambiguous codes study habits, for example, how they were involved in the peer leading sessions and how they performed the homework were retained as it provides relevant details pertaining to the quality of their study habits.

Course grades were converted into 4-point scale numbers for computing averages. For each student, percentage of attendance was calculated as the number of times the student recorded a
clicker response divided by the maximum number of times the student could record a response in the semester. Homework completion in the course was measured using percentages of completion of homework. Instead of homework grades, percentages of the homework completion were used to measure student effort. In order to make the scales of the four outcome variables consistent, test scores were transferred into percentages.

To examine the relationship between study habits and academic performance in college General Chemistry for at-risk students as compared to the non-at-risk students, scatter plots showing relationship between study percent and final exam score for the two groups were constructed. To determine statistical significance, a multiple regression was conducted where SAT math score, study percent, and the interaction between study percent and SAT math score were used to predict students’ final test scores. The reason for using final test scores in the regression model is that the study percentages represent studying across the entire term and the final exam was the only cumulative test.

The six interviews were transcribed verbatim using an open coding method. First, four chemical education researchers coded the transcripts independently; each person was assigned to code one to two distinct transcripts to describe all the themes present. The separate themes identified were compiled and the researchers discussed the similarities and differences among their themes to create a unified code list. Finally, two of the researchers coded the six transcripts independently based on the unified code list using NVivo 11.1.1 software. Upon completion of coding, disagreements between codes were discussed until consensus was reached.
Results

Descriptive statistics

To describe the relationship between study habits and academic performance for at-risk and non-at-risk, students who replied to the text message inquiries were considered. There were 122 students who replied to at least one quarter of the 28 text message inquires and these students were selected for the analysis as these students replied to a sufficient number of text messages to provide a picture of their studying habits. Using the aforementioned SAT math cut-off, 28 of these students were classified as at-risk and 94 were non-at-risk students. Descriptive statistics for these two groups are listed in Table 18.

Table 18. Descriptive statistics of at-risk and non-at-risk students in the selected sample

<table>
<thead>
<tr>
<th>Variables</th>
<th>Non-at-risk</th>
<th>At-risk</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>94</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>SAT math (Mean ± SD)</td>
<td>586 ± 51</td>
<td>483 ± 28</td>
<td>2.50</td>
</tr>
<tr>
<td>Test 1 (%)</td>
<td>69.9 ± 15.1</td>
<td>62.4 ± 13.4</td>
<td>0.53</td>
</tr>
<tr>
<td>Test 2 (%)</td>
<td>72.0 ± 14.6</td>
<td>66.2 ± 11.2</td>
<td>0.45</td>
</tr>
<tr>
<td>Test 3 (%)</td>
<td>53.2 ± 15.3</td>
<td>42.0 ± 11.9</td>
<td>0.82</td>
</tr>
<tr>
<td>Final Test (%)</td>
<td>49.1 ± 13.5</td>
<td>45.7 ± 15.8</td>
<td>0.23</td>
</tr>
<tr>
<td>Attendance (%)</td>
<td>83.1 ± 17.0</td>
<td>81.6 ± 21.0</td>
<td>0.08</td>
</tr>
<tr>
<td>HW (%)</td>
<td>94.0 ± 12.4</td>
<td>97.3 ± 6.2</td>
<td>0.34</td>
</tr>
<tr>
<td>Course GPA</td>
<td>2.76 ± 0.72</td>
<td>2.50 ± 0.61</td>
<td>0.39</td>
</tr>
<tr>
<td>Study Percent (%)</td>
<td>46.6 ± 25.4</td>
<td>61.6 ± 29.3</td>
<td>0.55</td>
</tr>
</tbody>
</table>

*Cohen’s d = 0.2 (small), 0.5 (medium) and 0.8 (large)

First, noting that comparison between Table 17 and Table 18 on the same variables shows that the selected sample and the broader population are very similar, supporting the ability of the sample to represent the population at least on the variables of interest. Second, the average study percent outside the class for at-risk students and non-at-risk students were 61.6% and 46.6%, respectively. It is interesting that the study percent for at-risk students was 15% higher than non-
at-risk students, which means at-risk students reported studying more frequently outside the class than non-at-risk students in our setting.

For each student, the percent of text responses that used a particular study habit was calculated and the average for each study habit for the non-at-risk and at-risk students are presented in Table 19. For brevity, only the study habit codes that represent at least 5% of the text responses are shown. The data in Table 19 suggests that the study habits employed by the at-risk students did not differ from the non-at-risk students in terms of relative frequency; however, the at-risk students did employ each study habit at a higher rate.

<table>
<thead>
<tr>
<th>Study Habit</th>
<th>Non-At-Risk Students</th>
<th>At-Risk Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reviewed notes or PowerPoint</td>
<td>18.3%</td>
<td>21.8%</td>
</tr>
<tr>
<td>Reviewed the textbook</td>
<td>15.4%</td>
<td>19.8%</td>
</tr>
<tr>
<td>Online homework</td>
<td>13.1%</td>
<td>18.0%</td>
</tr>
<tr>
<td>Practiced problems</td>
<td>6.6%</td>
<td>10.0%</td>
</tr>
<tr>
<td>Previous exams or study guides</td>
<td>5.8%</td>
<td>9.0%</td>
</tr>
</tbody>
</table>

**Study habits predicting academic performance**

To describe the relationship between study habits and academic performance for at-risk and non-at-risk students, scatter plots (Figure 13) and a linear regression were examined for each group separately. The scatter plots and regression analysis show little relationship between study percent and final exam score for non-at-risk students ($R^2=0.004$), in contrast to a moderate relationship between study percent and final exam score for at-risk students ($R^2=0.291$). This differential relationship indicates that the relationship between study percent and final exam score might be modified by SAT math.

To further examine the differential relationship, a multiple regression model was run using SAT math, study percent, and the interaction between SAT math and study percent to predict final
exam score. The interaction term was added to model the differential relationship. The multiple regression model is presented in Table 19 and suggests the linear best-fit equation of:

$$\text{Final test} = -0.339 + (0.00137 \times \text{SAT math}) + (0.939 \times \text{Study Percent}) +$$

$$(-0.00150 \times \text{SAT math} \times \text{Study Percent})$$

The prediction model statistically significantly predicts students’ final test, $F(3, 118) = 5.39, p = 0.002, R^2 = 0.121$, with a medium effect size $f^2 = 0.14$ (Cohen, 1988). All terms were significant ($p < 0.05$) except for the constant (Table 20).

![Scatter plots showing correlation between the study percent and final exam for non-at-risk and at-risk students](image)

**Figure 13.** Scatter plots showing correlation between the study percent and final exam for non-at-risk and at-risk students

<table>
<thead>
<tr>
<th>Table 20. Multiple Regression Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variables</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>SAT math</td>
</tr>
<tr>
<td>Study percent</td>
</tr>
<tr>
<td>Study*SAT math</td>
</tr>
</tbody>
</table>

The results indicate that both study percent and SAT math score are positively associated with final exam score. The interaction effect between study percent and SAT math is negative and
significant, indicating that the differential relationship observed earlier is unlikely to be attributed to chance. The effect of study percent on final test score depends on students’ incoming SAT math scores; in short, a high rate of studying can mitigate the impact of low incoming SAT math scores. To confirm that the results were also applicable for other students, the multiple regression model was also conducted on the participants who replied to the text messages at least once, with the same trend in results observed.

Figure 14 shows a diagram plotted based on the regression equation. The lines represent the relationship between study percent and predicted final test scores when students have different SAT math scores using 50-point iterations in the range of 500 to 650 (representing the 15th to 93rd percentile in the sample). In general, higher SAT math score leads to a higher score on the final test. However, the differences caused by SAT math scores in performance on predicted final test scores for students change dramatically by frequency of studying for students. For at-risk students (math SAT < 515) the frequency of studying outside the class played a more important role in predicting final test scores than those with higher SAT math.

Figure 14. Study habits predicting final exam scores
The differential relationship of frequency of studying with academic performance for different SAT math levels merits further study. One possible explanation is that students with different SAT math respond to earlier assessments in a different manner. For example, students with higher SAT math who perform well on the assessments throughout the term study at a relatively low frequency and continue to perform well on the final exam, possibly a result of seeing similar content in secondary school. However, when students of higher SAT math are not performing to their satisfaction, they respond by studying at a very high frequency. Students with lower SAT math may have an opposite relationship. Students with lower SAT math who perform well on early assessments may respond to the positive feedback by continuing to study at a high rate. However, if lower SAT students perform below their expectations, they may be discouraged and study less frequently as they do not expect to see a payoff from their efforts. This proposed explanation for the differential relationship essentially uses incoming SAT math scores and early academic performance as a proxy for students’ self-efficacy. The role of self-efficacy in terms of study habits for at-risk students will be explored in the second research question. To help understand the relationship between frequency of studying and academic performance in Figure 14, we also plotted the scatter plot for frequency of study and final exam scores of students (Figure 15). In Figure 15, different shapes represent the students who have different ranges of SAT math scores between 500 and 650 that are consistent with SAT math scores in Figure 14.
Figure 15. Scatter plot for study percent and final exam scores

Exploring at-risk students’ study habits through interviews

Table 21 lists demographic information, SAT math, final test score, predicted final test score (from the above regression), final course grade from General Chemistry I and table 22 lists the numbers of text message responses and study approaches of the six interviewees. Among the interviewees, four groups of at-risk students were found based on their study habits. The sections below include: a thematic description of each group based on text message responses and the open coding of their interview transcripts as described previously. Pseudonyms are used to protect the identities of interviewees.
### Table 21. Information of the six interviewees

<table>
<thead>
<tr>
<th>Name</th>
<th>Jack</th>
<th>Ellie</th>
<th>Mary</th>
<th>Bella</th>
<th>Lucy</th>
<th>Ava</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>Female</td>
<td>Female</td>
<td>Female</td>
<td>Female</td>
<td>Female</td>
</tr>
<tr>
<td>Race</td>
<td>White</td>
<td>Asian</td>
<td>White</td>
<td>Hispanic</td>
<td>Hispanic</td>
<td>Black</td>
</tr>
<tr>
<td>Major</td>
<td>Environ. Science</td>
<td>Physical Therapy</td>
<td>Pre-Medical Sciences</td>
<td>Biomedical Sciences</td>
<td>Biomedical Sciences</td>
<td>Biomedical Sciences</td>
</tr>
<tr>
<td>SAT math</td>
<td>510</td>
<td>460</td>
<td>430</td>
<td>510</td>
<td>490</td>
<td>510</td>
</tr>
<tr>
<td>Actual final test (%)</td>
<td>29</td>
<td>26</td>
<td>64</td>
<td>58</td>
<td>38</td>
<td>46</td>
</tr>
<tr>
<td>Predicted final test (%)</td>
<td>42</td>
<td>30</td>
<td>49</td>
<td>52</td>
<td>51</td>
<td>41</td>
</tr>
<tr>
<td>Final Grade General Chemistry I</td>
<td>C</td>
<td>C</td>
<td>A-</td>
<td>B</td>
<td>C+</td>
<td>B-</td>
</tr>
</tbody>
</table>

### Table 22. Information of the six interviewees

<table>
<thead>
<tr>
<th>Name</th>
<th># of text responses</th>
<th>Study approaches (Frequency*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jack</td>
<td>21</td>
<td>Homework (4), Textbook (3), Notes (2) and Study in groups (i*)</td>
</tr>
<tr>
<td>Ellie</td>
<td>28</td>
<td>Homework (4), Practice tests (1) and Study in groups (1)</td>
</tr>
<tr>
<td>Mary</td>
<td>24</td>
<td>Notes (11), Textbook (9), Practice Tests (6), Study in groups (6), Flash cards (3), Practice Problems (2), Visit instructor (1)</td>
</tr>
<tr>
<td>Bella</td>
<td>25</td>
<td>Homework (14), Textbook (5), Notes (2), Practice tests (2), Practice problems (1), Study in groups (i)</td>
</tr>
<tr>
<td>Lucy</td>
<td>27</td>
<td>Notes (18), Homework (11), Textbook (2), Practice tests (1), Online videos (1), Study in groups (i) and visit instructor (i)</td>
</tr>
<tr>
<td>Ava</td>
<td>28</td>
<td>Homework (4), Notes (4), Textbook (3), Practice Tests (1), Online videos (1), study in groups (i) and Flash cards (i)</td>
</tr>
</tbody>
</table>

*Numbers listed in the parentheses mean the number of times the study approach was mentioned in the text message responses, *"i" means the study approach only was mentioned in the interview

**Jack & Ellie**

Jack and Ellie were the two interviewees that knowingly did not study regularly according to their responses to the text message inquiries and interviews. Jack replied to 21 out of 28 text
message inquiries of which ten of them reported not studying, while Ellie replied to all 28 text message inquiries and indicated not studying 23 times. In the text message responses, both Jack and Ellie reported limited types of study approaches, and they mostly reported using single study approaches and occasionally combined two study approaches. The interview data align with these remarks. Except for the pattern of not studying, the common theme for Jack and Ellie in the interviews was using study approaches at the surface level when they were asked to articulate their study habits.

**Study approaches**

Although Jack reported using the textbook to study three times via text message response, the way Jack used the textbook was cursory with little evidence of seeking meaning: “I didn't do much with the textbook honestly…. I would just like, skimmed it” and “Going back in the book actually I don't even know…like at the end of chapters how they'll have like example questions… I never did those.” Jack described notes as a means to facilitate memorization, in line with a surface level approach “I just did the basics…reading over the notes, copying some of the notes just to help get a better memory of it…that's really all I did.” Jack did his homework with peers as it was easier to get help, if there were any hard questions, he could “just ask for help”, and he just wanted to “get the answer and move on”. He also relied on friends when he encountered unclear concepts; if his friends couldn’t help he showed no signs of attempting problems on his own: “I would go to friends, ask for their help…a lot of the times they would do that for me kind of thing…If they didn't know I would honestly just skip over it.”

Ellie did all the homework assignments and tried to solve problems on the practice tests, but she spent a considerable amount of time stuck on problems:
I go through the homework, I do the homework problems again…and then a test review I usually look at that and try to solve each problem…and then if I don't really get one problem, I sit there for like an hour, and I'm trying to like figure it out and I finally get it after five hours. (Ellie)

Like Jack, Ellie also reported relying on friends in her studying: “In college, I don't really know anything on chemistry so I depend a lot on my peers” and “in General Chemistry, I had my friend like be there every step of the way and help me.” Ellie’s feature of relying on others happened in different studying scenarios, for example, in the peer leading session:

In the peer leading everyone is inputting their own ways of how to do it…but I like to get the right answer from the main person [peer leader], know I'm learning it right, rather than trying to figure it out and do it wrong and then I learn it wrong and remember it wrong.

(Ellie)

When she was not sure about a concept in her studying, she also still ended up seeking help from others: “I either like sat there and cried or I would go try to like find it online and see if they could explain it. And if I still didn't get it and I went to like one of my peers and I was like, ‘Hey, explain this to me’ and then after like a while I finally got it.” One anecdote in Ellie’s interview further evidenced a surface approach to studying. When asked to nominate the most interesting things she learned in General Chemistry I, she responded: “The most interesting thing I learned…I don't know…it's bad but I don't really remember like what it was in General Chemistry, I learned.”
Metacognition

Jack and Ellie showed little reflection on their own study approaches. Jack thought homework and studying in groups were helpful and Ellie believed all the study approaches she used were helpful. When asked if he had plans to change his study approaches, Jack said he didn’t have plans to change his study approaches: “I feel like my habits will probably like be the same…I guess like really the effort is like the main thing that was kind of my problem last semester.” Ellie asserted that she would do more independent work: “I needed to probably do more independent work because I'm kind of depending on peers now to help me.” For the text messages both showed contradictions in their reflection. Jack asserted the messages “reminded me to study and gave me more of a motivation to get it done” despite frequently indicating not studying; Ellie said text messages reminded her to study but added that the messages did not influence her studying: “It [the text message inquiries] didn't really influence me, it kind of reminded me I need to study”.

Affective factors

Both Jack and Ellie expressed low self-efficacy in chemistry. In the interview, Jack said: “I'm not that good in chemistry so my confidence for that just in general, is pretty low.” Ellie described herself as a slower learner in learning chemistry:

I mean the concept of molality and molarity, I know this is kind of sad and embarrassing for me but it took me about a week to be able to distinguish the two. I'm a slow learner…I'm not confident because it'll take me forever to learn one topic. (Ellie)

Interestingly, Ellie mentioned that she was more confident in the General Chemistry II course, a difference she attributes to having a different instructor. In terms of interest, both of them
stated that were not interested in chemistry, “Like I'm a science fan. But chemistry, not so much” (Jack) and “not so much [interest] in chemistry.” (Ellie)

In summary, Jack and Ellie both describe surface approaches and low self-efficacy regarding chemistry, exhibited by the belief that they could not solve problems on their own, and a reliance on others as a coping strategy. In the Learning Approaches Framework for Chemistry, both Jack and Ellie provide indications of the first two levels by seeking to memorize facts and rely on others for answers. This could also explain the infrequent studying exhibited throughout the semester. As seen in Table 21, both Jack and Ellie finished with a C, the lowest possible grade available given the selection criteria of enrollment in the follow-on course.

**Mary & Bella**

Mary and Bella reported studying regularly according to their responses to the text message inquiries and interviews. Mary replied to 24 text message inquiries with 20 of them reporting studying and Bella replied to 25 text message inquiries with 24 of them reporting studying. The study approaches reported by Mary and Bella were much more diverse than those reported by Jack and Ellie. Bella tended to use one single approach at a time when studying, while Mary used multiple approaches. Here is an example of Mary’s text message response: “Yes. Reviewed old test, practice problems, flash cards, read the book and reviewed notes”. Mary and Bella not only studied consistently, but also showed signs of a deep level of study approaches when they described their study approaches during the interview.

*Study approaches*

Mary used the textbook to clarify concepts that were not clear for her, along with example questions and practice problems in the textbook. “I like to use it [the textbook] to review the
concepts in cases where her [the instructor’s] notes weren’t helpful, [I wanted to] see if I can get it explained a little bit better” She said she would “have them [problems in the textbook] totally worked out” and “repeated those by myself and compared”. For the homework, Mary would study beforehand and then do it as a quiz, and she used her notes to help when she got stuck. She always saved the last homework assignment for the days before the test and practiced problems on the homework assignment.

The homework, is kind of like my self-quiz…so I study a little bit and then do that [homework], so if I can do on my own, and tell myself I am doing good, and then would I need help, I have my notes for it, that is the concept I start reviewing.

She marked things she didn’t understand when studying and brought them to the instructor in the office hour. “I didn't go every week, but during test week, I make an appointment to go there at least once, sit with her, review things that I circle or mark that I don't understand.”

In the interview, Bella didn’t articulate many details about how she used each study approach, but her answers to some of the questions projected that she adopted deep level approaches. For example, she said that when she was unclear about concepts, she searched online or went to ask peers, but she would not rely on them, in contrast to Jack and Ellie. “When I don't understand a problem obviously I go to my peers but I don't rely just on them and just study with them. Like I'll study maybe twice with them and then as the exam approaches closer I'll just focus on studying alone.” In addition, like Mary, Bella asked her instructor for help after making her own attempts. “I would go to her office hours during that week [the week of exams]. And then I would take my practice exam with me and then ask whatever I have problems with”.

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Another theme in common for Mary and Bella is both of them liked to help others when studying in groups, and they thought helping others could help themselves learn better. When describing the interaction with others in a group, Mary likes tutoring others because it helps her too: “I prefer to study in group, …I end up knowing more so I tutor, I am like tutoring everyone, it helps me cause I teach it I know it.” Bella described a mutually beneficial relationship between her and her peers. “If you have a problem, you can go to your peers… They can explain it to you, and they have a problem, you can help them, also when you are helping people, you are kind of learning yourself.” In summary, both Mary and Bella provided a description that matches Level 3 where students develop their own understanding and use interactions with others primarily to confirm their understanding.

Metacognition

Mary and Bella showed much more reflection on their study approaches compared to Jack and Ellie. Mary thought studying her notes, practicing problems and taking practice tests were helpful for her to study. One study habit that she particularly liked was tutoring others about chemistry concepts, she believed that helping others could help her learning and had a substantial influence on her study. “It is mostly me helping other people, [if my friends] need a concept just clear or something [I can help them], and that is huge for me, cause I teach, if you can do that, you got it, you would be fine… So that is a huge influence on my study habit, so I love it.” Bella thought lecture notes, peer leading sessions and group work were helpful. Bella expressed that she is studying more consistently in the General Chemistry II course instead of cramming: “[This semester] I am studying more ahead of time, and learning from last semester [that I should] not just leave it for the last week.” This reflection is particularly telling given Bella’s consistent studying reported by the text messages in General Chemistry I. Either Bella planned to increase
her frequency of studying beyond her consistent approach earlier, or her reflection of her studying consistency in General Chemistry I was not accurate. Bella also indicated she would keep most of her study approaches except for using the textbook more and trying to read through the whole chapter in the textbook.

For the text messages, both Mary and Bella thought they were reminders of studying. Mary kept track of her text message responses and she used them to reflect on her study habits. “I found it [the text message project] was helpful… try to improve myself by writing things down, like what I would do differently, you really see what you are doing instead of just doing it.” Bella also expressed that text messages helped her to study more. “It [the text message project] did help me a lot and like doing a lot of stuff after class and reading the notes. So it did remind me to do all that kind of stuff.”

**Affective factors**

Mary and Bella both showed higher self-efficacy with General Chemistry I and expressed interest in chemistry as a subject or certain topics in chemistry. “I used to hate chemistry and took General Chemistry 1 honestly and then I loved it all of a sudden, just worked out… I would say I really like molecular geometry… it made me fall in love with chemistry” (Mary), and “I'm not like overly confident, and I'm not like I'm scared or like nervous about it that much…I really like doing Lewis structures, I thought it was fun” (Bella).

**Lucy**

Lucy reported studying regularly, as she replied to 27 text message inquiries with 24 times reported that she was studying. However, the interview revealed that Lucy adopted a surface level study approach.
Study approaches

Lucy mentioned diverse study approaches in her studying, but for most of them, she used them in a surface level when asked to explain them. For example, in the interview, Lucy described herself as “not a textbook person” and “there was so much information and then there were things worded in ways that sometimes I'm like I don't understand what they're trying to say.” For the notes, she asserted that she would “read over them and in those notes there was practice problems and I always highlighted stuff.” For homework and practice tests, she just mentioned that she used these for practicing problems without further descriptions. Lucy did not like to interact with peers outside the class, because she mentioned that “most interaction I have is when we are working on like on clicker problems.” Like Jack and Ellie, Lucy described her role in groups as relying on others for building knowledge, as she describes group work: “I think that you get more knowledge on things that we are doing, you get help if you don't understand something.” Lucy described her study approaches mainly as mainly gathering facts and relying on others, providing evidence of Level 1 and Level 2 learning approaches in the framework.

Metacognition

Lucy reflected on her study approaches and showed moderate metacognitive skills over her studying. Regarding plans to change, she said she actually has taken a different approach on learning General Chemistry II, do less cramming and study more consistently: “I guess that I am taking it step by step…last semester I would cram some information, now every day I review my notes and review the Power Points and try to do at least five practice questions before my exam.” She also said she would use more outside resources like tutoring and help from friends. Lucy described the text messages as motivation for her to study: “whenever I got the message or the text, I was like, oh snap, I need to study it, and then that would like motivate me to study”.

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Affective factors

Lucy described herself as having average confidence in learning chemistry, but she has become more confident in the General Chemistry II course because of studying. “Interviewer: how confident are you in chemistry, in general? Lucy: On a scale of 1 to 10, I'd say a 6…. maybe because I'm studying more, I'm more confident this semester than I was last semester.” She said she never reads about science or chemistry beyond what is covered in the course even though she thinks the intermolecular force topic in chemistry is interesting to her when asked to nominate one. In contrast to Jack and Ellie, Lucy’s confidence in this regard can be described as more malleable and may represent sufficient self-efficacy to study even in light of her reported challenges in approaching the content.

Ava

Ava was an interviewee who didn’t study regularly and used cramming to study chemistry. She replied to all 28 text message inquiries with 19 of them describing not studying, and the 9 text messages that described studying happened leading up to the test dates. However, when Ava articulated her study approaches in the interview, she employed deep level study approaches even though her study frequency was on the low end.

Study approaches

Ava expressed that she read the textbook in depth, especially in the week of the test. She liked to make use of the end of chapter summaries, and occasionally she would do example problems in the textbook:
I felt like it explained everything and then even in the end of the chapter it gave short block summaries of different concepts or whatever, so after you read them in depth, even if you didn't understand it in depth, you could flip to the back of the chapter and have like little sections like that, that helped a lot and especially I happened to be in a situation where I was cramming, I could always flip to those sections, so I really relied on the textbook. (Ava)

Ava also described an active approach for lectures: “I print out the lectures ahead of time and I write my notes on the actual slides and then I can like actually point out what's important”. She described the interaction between herself and others as two types. First, in working with her peer leader, she shows self-efficacy in putting forth her own understanding: “I would ask my TA during the peer meeting, or if I didn't understand something I would go to him and be like…ok, well, if I do it this way, am I right or wrong, and that would that help me.” Second, when working with her friends, she could help others and others could also help her. “So it's like I know A, you know B, and now we can put it together. In the situation now I did really well on the first test, so it's just like ok I can help somebody else”. In terms of approaches to learning, Ava shows signs of confirming understanding, analogous to Level 3 in the learning approaches framework, even with her infrequent reports of studying.

**Metacognition**

Ava reflected on her study approaches and showed indications of metacognitive skills. She thought flashcards and group work were helpful for her. She has also planned to change her approach in General Chemistry II: “I didn't try to put together as the full picture until I got to General Chemistry II, and I realized that would probably help more trying to put the little pieces together to a big picture.” For the text messages, she said that they were good reminders and also a
cause for change: “I would look at all my past text messages and see that I replied ‘no’ seven or eight times and I’m just like maybe I should open my textbook and at least look at something.”

**Affective factors**

Ava described not being confident before General Chemistry I because she felt her prior knowledge in chemistry was not strong, but felt more confident after General Chemistry I as she has learned more knowledge in chemistry. “I feel pretty confident now [in General Chemistry II], before coming into college, especially right before my general chemistry I, I was really hesitant on it because my chemistry background wasn’t that great.” Ava expressed interest in chemistry, she likes to read articles related to chemistry concepts, search chemistry concepts online and find related articles she was interested in until she understands the concepts.

**Discussion: Cross-Case Analysis**

Analysis across the six interviews combined with the text message responses of the six interviewees showed that both the frequency and quality of studying matter for at-risk students’ academic performance in college General Chemistry. The quality and frequency of studying for the six interviewees are represented in Figure 15. In fact, for these six students, different mixtures of these two features of study habits direct different academic performance. First, the two students who meet both criteria (high frequency and high quality) earned the highest grades of the six cases (see Table 21). Both Mary and Bella studied more regularly over the General Chemistry course, and they also employed deep level study approaches when studying chemistry. It is likely that these study habits helped them earn good grades in the course despite their at-risk status. Mary, in particular, entered the course with the lowest SAT math of the six cases (and second lowest among the sample of 122 students) and finished the course with a grade of A-. Second, when neither high
frequency nor high quality of studying is present, at-risk students would likely perform poorly. This description would match the cases of Jack and Ellie in the study. Both of them knowingly did not study regularly and described surface level study approaches; these study habits led to the lowest possible grade in this cohort.

Third, when only one of the criteria is met, the quality of studying may matter more than the frequency of studying. Ava, who studied less frequently but adopted deep level study approaches performed better on her final course grade than Lucy, who studied more frequently but used surface level study approaches. Similarly, Ava over-performed her predicted final test score while Lucy under-performed her predicted score. According to the data analysis of the four groups in our study, we proposed a hypothetical model that both the frequency and quality of the study habits can be closely related to at-risk students’ academic performance, and the quality of study habits might be more important than the frequency of the study habits. However, this model has to be tested by a bigger, more diverse sample in order to propose a generalizable claim. Determining the relative importance of quality versus frequency remains an open question that will be important to better understand how to assist at-risk students.
Figure 16. Distribution of the quality and frequency of studying of six interviewees

The interviews were consistent in that examples of good metacognitive skills and positive affective factors coincided with higher quality studying. For example, students’ self-monitoring of their study approaches was only present for students who indicated deeper level studying approaches: Mary recognized that tutoring others helped her own learning and Ava realized that she needed to make connections among chemistry topics and not just memorize them as separate facts. Mary and Ava also kept track of their text message responses and utilized them to help promote their studying. In addition, high achieving students Mary and Bella showed more self-efficacy in learning chemistry and more interest in chemistry than low achievement students Jack and Ellie. Interestingly, both Lucy and Ava mentioned that they were not confident in General Chemistry I, but after General Chemistry I, the level of confidence increased because of studying. It seems likely that self-efficacy and frequency of studying are interrelated, where increases in one can beget increases in the other. In sum, students’ metacognitive skills and affective factors such as self-efficacy and interest in chemistry can help us understand why and how at-risk students can succeed in chemistry. These traits are closely related to students’ study habits (frequency and quality), which impacts their academic performance.
Limitations

The number and representativeness of the students in this sample serve as a limitation to the results presented. The multiple regression analysis was conducted on 122 students, of which only 28 were considered at-risk based on SAT math. The sample size is sufficient to provide statistical significance and the sample was seen as comparable to a broader population in terms of the measures of interest (see comparison of Tables 17 and 18). However, it is possible that this relationship is particular to the research setting and replication is necessary to further an understanding of how generalizable the claims made are. The interviews conducted provided an exploration into the variety of frequency and quality in study habits, but cannot provide a generalizable statement regarding the likelihood of each combination. For at-risk students, our initial research question was what are the study habits for at-risk students in General Chemistry I and how do they influence their study habits in General Chemistry II. We sent invitations to 28 at-risk students who participated in the text messages project and were currently enrolled in General Chemistry II. These 28 students replied to at-least one quarter of the text message inquires, because we asked them to elaborate the study approaches they reported through text messages. From the students who volunteered to participant, we selected six of them based on the time they replied to us. We also considered gender, race, major and final grade in General Chemistry I, and selected the interviewees as diverse as possible based on the above variables. By interviewing a heterogenous group of at-risk students, hopefully we can understand each student’ study habits in depth and get variation on at-risk students’ study habits. Whether or not we have reached interview saturation to include all types of study habits for at-risk students in the setting is still an open question. Follow-up investigations into the relationship between frequency and quality of
study habits to academic performance with large sample sizes from a quantitative perspective would be necessary to further an understanding of these characteristics.

Additionally, the interviews conducted only examined factors related to student self-efficacy and metacognition in seeking to understand characteristics that can explain study habits. Other student factors such as time available to study, perceptions of knowledge generation or familial / social expectations for education may certainly prove to be relevant in understanding study habits. Finally, the interview cohort did not include students who failed or withdrew from first-semester General Chemistry and these students may provide unique, additional characteristics of study habits for at-risk students.

Conclusions and Implications

This study classified at-risk students and non-at-risk students according to their SAT math scores. As expected from the research literature, the at-risk students performed worse on each of the in-class measures of chemistry learning. The data also showed that at-risk students put in as much effort in terms of attending class and completing homework, and reported studying outside of class at a higher rate. This may indicate that the at-risk students perceive a lack of preparation and subsequently study more. Results of multiple regression showed that studying frequency plays a more important role in student academic performance in college General Chemistry for the students who have lower SAT scores as compared to students who have higher SAT scores.

Furthermore, findings through text message responses and interviews suggested that both the frequency and quality of studying are important to academic performance for those at-risk students. The results of this study lead to several implications for instructors who are teaching college chemistry courses. First, instructors should encourage at-risk students to believe they can
succeed by studying (Cook et al., 2013). More importantly, instructional supports should be developed to promote at-risk students studying more and to develop deep level study approaches. In order to increase the frequency of studying, instructors can suggest students keep records of when and how they study in certain time ranges, and use those records to keep track of their study. The text message methodology presented here is one possible approach for doing so.

For the quality of studying, it is essential for instructors to help students develop deeper level study approaches. Instructors can provide specific guidance for at-risk students to use study materials, for example, by making annotated notes while reading the textbook or working the practice problems in the textbook. Likewise, for lecture notes, students can be encouraged to read the notes before the lectures and take their own notes during the lecture to support understanding the content instead of capturing all that is said. After the lectures, it is better to actively summarize or rewrite notes using a student’s own words instead of only reviewing the notes taken. In terms of practicing problems, the Learning Approaches for Chemistry framework’s emphasis on students generating their own understanding and using others primarily to confirm their understanding is prescient. Thus, efforts to promote students attempting to practice problems independently before comparing with an answer key or asking for help would be recommended. In terms of group work, the successful at-risk students presented here demonstrated independent learning by helping others in groups or using groups to confirm their understanding. The importance of explaining concepts when participating in a group matches learning theories and past research on how group work is effective. (Slavin 1996, Webb 1989 & 1992). An instructional implication that follows would be the practice of assigning and rotating roles within the group, where one role has an explicit function of providing explanations when the group is called upon.
For researchers who are interested in designing interventions aimed at helping at-risk students, improving the frequency and quality of study habits are appropriate targets. Past research reviewed herein has described promising intervention techniques that may improve study habits. Future research can be aided by matching these interventions with measures to assess students’ study habits with the methodology used here as one potential path for doing so. Another potentially fruitful area for research is to investigate the impact of pedagogy and classroom environment on students’ study habits.

Acknowledgments

Partial support for this work was provided by the National Science Foundation’s Improving Undergraduate STEM Education (IUSE) program under DUE-1432085. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

References


Chan, J. Y. K. & Bauer, C. F. (2016). Learning and studying strategies used by General Chemistry students with different affective characteristics, Chemistry Education and Research Practice, 17, 675-684.


CHAPTER VII:
CONCLUSIONS AND FUTURE DIRECTIONS

Conclusions

The overarching goal of this dissertation is to understand student learning and experiences in post-secondary General Chemistry with the aim of improving STEM education. To address this goal, multiple novel measurement tools were developed and implemented to measure student learning and experiences in post-secondary chemistry. More specifically, students’ content knowledge and study habits were explored in this study. Evidence of students’ linking concepts and effective study habits of students was obtained and discussed.

First, two assessment tools, Creative Exercises and Measures of Linked Concepts, were examined in General Chemistry courses. Evidence of student responses to these two assessment tools showed that Creative Exercises and Measures of Linked Concepts could be used to measure, and therefore promote linking knowledge in a post-secondary General Chemistry setting. Each of these two assessment tools has unique characteristics in terms of measuring linked concepts. The open-ended nature of Creative Exercises makes it a more student-centered assessment, that is, students choose the content they would like to present when responding to a Creative Exercises prompt. Creative Exercises can measure not only students’ correct linking across concepts in General Chemistry courses, but also reveal misconceptions towards learning General Chemistry, in particular, misapplications of chemistry models. Measure of Linked Concepts consists of
similar prompts and a series of statements requiring students to evaluate providing flexibility for instructors regarding what prior content they want to measure during certain times in the course. The closed-ended (true or false) nature of this measurement tool allows instructors to determine the prevalence of correct and incorrect links made by students, and also makes Measure of Linked Concepts an appropriate assessment tool for large classes (greater than 100 students).

Second, text message inquires were used as a novel tool to measure students’ study habits over one semester. Analysis of the text message responses showed the feasibility of using text message inquires to collect data on General Chemistry students’ study habits. Student response patterns match the expected trend; the percent of students reporting studying peaked immediately preceding the exam dates and decreased after the exam dates. Participants in the study were divided into three groups with comparable group size based on their study habits using cluster analysis, students who knowingly do not study, students who describe mandatory course requirements as studying and students who describe studying in addition to the mandatory course requirement. The last group outperformed the other two groups on a common exam. The students who describe mandatory course requirements as studying performed similarly on the exam with the group of students who knowing do not study. To document the change in study habits across the semester, we analyzed text message responses to the four inquires that were sent out immediately preceding each of the four exams from a common group of students. Results showed changes in student study habits, a potential sign that students adapt their study habits across the semester, probably due to the course content, the nature of the exams, and maturational efforts of students.

Finally, the study habits of students who are at-risk of failing General Chemistry based on SAT math scores were also investigated. Compared to the non at-risk students, at-risk students put
in as much effort for learning chemistry in the setting, but performed worse on exams. Analysis of dichotomization of text message responses showed that the difference between at-risk and non-at-risk students on final exam scores narrowed down by high frequency of studying. Combination of text messages and interviews of six at-risk students showed both frequency and quality of study play a role in their academic performance, and the quality might matter more. The quality of studying refers to surface or deep level of study approach. Evidence for surface level study approach involves not working with others, asking for direct answers to problems from others, and memorizing facts for learning. Students who employ a deep level approach, including working cooperatively with others, working independently before confirming understandings, and explaining things to others, are more likely to perform better in courses. The study also found better metacognitive skills and affective factors including self-efficacy and interest of students toward studying chemistry are related to academic performance. Students who reflect and evaluate their study habits and tend to change unhelpful study habits, and those who with higher self-efficacy and interest in chemistry tend to perform better.

This work highlights the importance of using novel tools to understand students’ learning in General Chemistry. The findings in this work present a clearer picture of students’ conceptual learning in General Chemistry and how they study outside the classroom. In addition to understanding student learning in post-secondary chemistry, the novel tools presented in this work also offered alternative measurement tools in chemistry education research.

**Limitations and Future directions**

When interpreting the findings in this work, some limitations of this work need to be addressed. First, we collected different sources of evidence for the validity of proposed
measurement tools (see Chapter II), however, it is always worth collecting more evidence to support the validity of the measurement tools when implementing them in different settings. More specifically, for Creative Exercise and Measures of Linked Concepts, it would be worthwhile to explore long-term impact of using these assessments in General Chemistry on concept retention and academic performance in subsequent upper level chemistry courses. This would contribute to the consequential validity of the assessments. The evidence for validity after the “Unsure” option is added to Measures of Linked Concepts, especially whether the added option helps with minimizing chance of guessing, will be worthwhile to investigate.

Second, the generalizability of the findings may be limited by the sample and context. We used the students who have the available data for relevant variables. This led to the number of students in certain analyses as not very large, for example, for the at-risk students who responded to the majority of text messages (N=28). Also, we selected at-risk students using SAT math scores. Other student characteristics such as high school GPA or placement test scores might be appropriate to be used to identify at-risk students as well (Carmichael et al., 1986; Russell, 1994). Therefore, the sample of at-risk student may not be representative of the at-risk student population at the setting. Additionally, it is important to note that our findings were obtained in a four-year, public universities. It is possible that student responses to the tools used in this work are restricted to characteristics of the undergraduates within these universities. For other types of intuitions like community universities or institutions that have very different student profiles (e.g. SAT math scores, percentages of gender or underrepresented minority), caution is warranted when applying the findings from this work to those settings.

Third, we focused on SAT scores and demographic characteristics when comparing participants and non-participants. However, other confounding factors such as student motivation
or socioeconomic status may also influence students’ study habits and academic performance. Those factors are worth considering as well in future studies. For instance, Terrion and Daoust (2012) administrated a supplemental instruction program in college introductory chemistry, math, physics, and biology. To control for student motivation, the Academic Motivation Scale (Vallerand et al., 1992) was implemented to all the students in these courses. They compared the impact of the program by comparing attendees and non-attendees on final grades and withdrawal rates. They found attendees were more likely to persist in their studies but didn’t earn higher grades after controlling for student motivation.

As informed by this work, a number of future directions are worthwhile to be investigated. One of the most interesting and relevant areas of future work would be an investigation on the interplay relationship between different types of assessments and students’ study habits in chemistry courses. Students adjust their learning based on how they are assessed (Gibbs & Simpson, 2004). Incorporation of different types of assessments will help instructors gather evidence on students’ learning from multiple perspectives. Different types of assessments used in chemistry courses by instructors might change students’ study habits outside the classrooms. For example, Creative Exercises may promote student practicing more open-ended questions, Measure of Linked Concepts might lead students to spend more time reviewing prior concepts through textbook or notes, and group quizzes or group assessments may direct students to study more with their peers outside the classroom. Meanwhile, student performance on different types of assessments might be mixed depend upon which study habits students use. Certain study habits might be more favorable for some types of assessments. If students know how to choose the suitable study habits for assessments, the chance for them to succeed in a chemistry course may be greatly increased. For instance, Bunce et al. (2017) recently reported that students’ choice of
study resources depended upon the type of assessment in General Chemistry at United States Naval Academy. Through examining survey items from students, notes (including personal or instructor provided notes) were the most frequently used study resource by students for preparing instructor-written assessments (primary open-ended questions), but a majority of the students reported using prior assessments as their main study resource for preparing for the departmental multiple-choice common exams. This result indicated that one of the assumptions mentioned above, that different types of assessments might be one of the factors that influence students’ study habits, may be valid. It is worthwhile to investigate how students use these study resources based on the types of assessments and how it can alter students’ academic performance.

Another area of future work hinted by this work would be using text messages as a tool to design and evaluate interventions to promote study learning in chemistry. Research studies have reported on the efficacy of interventions that improved student academic performance through training on effective study strategies (Weinstein, 1998; Schunk & Zimmerman, 1998; Cook et al., 2013). However, the lack of direct measures on study habits of students in these studies makes it impossible to rule out the possibility that students’ performance might be improved due to some other students’ characteristics. Incorporation of a measure of study habits may provide support for a causal relationship between the efficacy of interventions and student study habits. The results of feasibility of using text messages to measure student study habits provides a potential measurement tool for studies that need to evaluate the effect of interventions with regards to students’ study habits. In addition, sending out text messages to students itself might serve as an intervention. Text messages can be used to remind students to study chemistry consistently, provide resources for learning chemistry, coach effective study approaches or foster good metacognition skills. Those messages might help students find the paths for success or clean up
obstacles on the way of learning chemistry. It is worthwhile to explore the efficacy of the above types of text messages on student learning and academic performance.

Finally, a model that describes both the frequency and quality of studying matter for at-risk students’ academic performance in chemistry is proposed in this work. This tentative model led to multiple implications and future directions for teaching and research. First, to increase the frequency of studying for students, instructors may provide additional materials such as extra practice problems or previous exams. In doing so, students would have extra resources to work when they complete the mandatory component for the course. Instructors can also ask students to keep track of study time and share them in class. These might promote more student studying as a result of being aware of how much time their peers spend studying chemistry. Instead of letting students take control of their study, instructor may use more proactive approaches like increasing the number of exams or using a substantial number of small quizzes to promote studying. Second, to develop deep level approaches for students, the Learning Approaches for Chemistry framework (Sinapuelas & Stacy 2015) emphasizes on students form their own understanding instead of relying on others for studying. Efforts like asking students to make their own annotated notes after each class, providing more opportunities for explaining through writing, video making or group activities, giving time or encouraging students time to think independently before comparing answers to others would be beneficial for building understanding in chemistry. Last, for researchers, it is worthwhile to explore the generalizability of the proposed model regarding the integrated effect of frequency and quality in studying chemistry. This model was exploratory and described with details using qualitative approaches in this work. Follow-up quantitative investigations into the effects of different combinations of these two aspects on academic
performance with a large number of students in chemistry would be necessary to further an understanding of the generalizability of the proposed model.

References


APPENDICES
Appendix A: Commonly used Acronyms

Table 23. Description of Commonly used Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full name</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEM</td>
<td>Science, technology, engineering, and mathematics</td>
</tr>
<tr>
<td>CEs</td>
<td>Creative Exercises</td>
</tr>
<tr>
<td>MLCs</td>
<td>Measure of Linked Concepts</td>
</tr>
<tr>
<td>rSPQ</td>
<td>Revised Study Process Questionnaire</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>MANOVA</td>
<td>Multivariate Analysis of Variance</td>
</tr>
<tr>
<td>GPA</td>
<td>Cumulative Grade Point Average</td>
</tr>
</tbody>
</table>
Appendix B: Institutional Review

October 4, 2013

Scott Lewis, PhD
Chemistry
4202 E. Fowler Ave.
CHE205
Tampa, FL 33620

RE: Exempt Certification
IRB#: Pro00014654
Title: An investigation into the prevalence of chemistry conceptions.

Study Approval Period: 10/4/2013 to 10/4/2018

Dear Dr. Lewis:

On 10/4/2013, the Institutional Review Board (IRB) determined that your research meets USF requirements and Federal Exemption criteria as outlined in the federal regulations at 45CFR46.101(b):

(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

As the principal investigator for this study, it is your responsibility to ensure that this research is conducted as outlined in your application and consistent with the ethical principles outlined in the Belmont Report and with USF IRB policies and procedures. Please note that changes to this protocol may disqualify it from exempt status. Please note that you are responsible for notifying the IRB prior to implementing any changes to the currently approved protocol.

Approved Document:

[IRB Research Protocol.docx]
The Institutional Review Board will maintain your exemption application for a period of five years from the date of this letter or for three years after a Final Progress Report is received, whichever is longer. If you wish to continue this protocol beyond five years, you will need to submit a new application at least 60 days prior to the end of your exemption approval period. Should you complete this study prior to the end of the five-year period, you must submit a request to close the study.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

Kristen Salomon, Ph.D., Vice Chairperson
USF Institutional Review Board
6/18/2014

Scott Lewis, Ph.D.
USF Department of Chemistry
4202 E. Fowler Ave. CHE205
Tampa, FL 33620

RE: Expedited Approval for Initial Review
IRB#: Pro00017861
Title: Improving Large Lecture Gateway Chemistry Courses through Flipped Classes with PeerLed Team Learning (NSF #1432085)

Study Approval Period: 6/18/2014 to 6/18/2015

Dear Dr. Lewis:

On 6/18/2014, the Institutional Review Board (IRB) reviewed and APPROVED the above application and all documents outlined below.

Approved Item(s):
Protocol Document(s):
IRB Research Protocol Gateway Courses.docx

Consent/Assent Document(s)*:
IRB Gateway Informed Consent.docx.pdf

*Please use only the official IRB stamped informed consent/assent document(s) found under the "Attachments" tab. Please note, these consent/assent document(s) are only valid during the approval period indicated at the top of the form(s).

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review procedure authorized by 45CFR46.110
and 21 CFR 56.110. The research proposed in this study is categorized under the following expedited review category:

(5) Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis).

(6) Collection of data from voice, video, digital, or image recordings made for research purposes.

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Your study qualifies for a waiver of the requirements for the informed consent process for records review, as outlined in the federal regulations at 45CFR46.116 (d) which states that an IRB may approve a consent procedure which does not include, or which alters, some or all of the elements of informed consent, or waive the requirements to obtain informed consent provided the IRB finds and documents that (1) the research involves no more than minimal risk to the subjects; (2) the waiver or alteration will not adversely affect the rights and welfare of the subjects; (3) the research could not practicably be carried out without the waiver or alteration; and (4) whenever appropriate, the subjects will be provided with additional pertinent information after participation.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

[Signature]
John Schinka, Ph.D., Chairperson
USF Institutional Review Board
Informed Consent to Participate in Research Information to Consider Before Taking Part in this Research Study

IRB Study # _Pro00017861___

You are being asked to take part in a research study. Research studies include only people who choose to take part. This document is called an informed consent form. Please read this information carefully and take your time making your decision. Ask the researcher or study staff to discuss this consent form with you, please ask him/her to explain any words or information you do not clearly understand. We encourage you to talk with your family and friends before you decide to take part in this research study. The nature of the study, risks, inconveniences, discomforts, and other important information about the study are listed below.

Please tell the study staff if you are taking part in another research study.

We are asking you to take part in a research study called:

*Improving Large Lecture Gateway Chemistry Courses through Flipped Classes with Peer-Led Team Learning (NSF #1432085)*

The person who is in charge of this research study is Scott Lewis. This person is called the Principal Investigator. However, other research staff may be involved and can act on behalf of the person in charge.

The research will be conducted at the University of South Florida.

This research is being sponsored by the National Science Foundation.

Purpose of the study
The purpose of this study is to:

better understand the impact of pedagogical reform in gateway courses in chemistry on students’ academic performance and persistence in STEM disciplines.

Study Procedures
If you take part in this study, you will be asked to:

Participate in one interview of approximately one hour in length (not to exceed 75 minutes). The interview will be conducted in a secure research laboratory at the University of South Florida. The interview will be audiotaped with your permission. The interview will cover applications of topics that you have seen in General Chemistry and/or Organic Chemistry. The
Tapes will be maintained for the extent of the study (estimated to be two years) and will be erased five years after the conclusion of the study.

**Total Number of Participants**

About 20 individuals will take part in this study at USF.

**Alternatives**

You do not have to participate in this research study.

**Benefits**

We are unsure if you will receive any benefits by taking part in this research study.

**Risks or Discomfort**

The following risks may occur:

- The interview questions regard chemistry knowledge and you may be uncomfortable with the interview process. Should you be uncomfortable, you can withdraw from the study at any time.
- There is a minimal risk that the data collected in this interview can become accessible by a member outside of the research team. To minimize this risk, all data will be stored in a locked research laboratory and identifying information will be replaced with pseudonyms.

**Compensation**

You will be paid a $35 gift card if you complete the one scheduled study visit. If you withdraw for any reason from the study before completion you will not be paid.

**Privacy and Confidentiality**

We will keep your study records private and confidential. Certain people may need to see your study records. By law, anyone who looks at your records must keep them completely confidential. The only people who will be allowed to see these records are:

- The research team, including the Principal Investigator, study coordinator, and all other research staff.
- Certain government and university people who need to know more about the study. For example, individuals who provide oversight on this study may need to look at your records. This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights and your safety.
- Any agency of the federal, state, or local government that regulates this research. This includes the Food and Drug Administration (FDA), Florida Department of Health, and the Department of Health and Human Services (DHHS) and the Office for Human Research Protection (OHRP).
- The USF Institutional Review Board (IRB) and its related staff who have oversight responsibilities for this study, staff in the USF Office of Research and Innovation, USF Division of Research Integrity and Compliance, and other USF offices who oversee this research.
• The sponsor of this study: the National Science Foundation

We may publish what we learn from this study. If we do, we will not include your name. We will not publish anything that would let people know who you are.

Voluntary Participation / Withdrawal
You should only take part in this study if you want to volunteer. You should not feel that there is any pressure to take part in the study. You are free to participate in this research or withdraw at any time. There will be no penalty or loss of benefits you are entitled to receive if you stop taking part in this study. The decision to participate or not to participate will not affect your student status.

New information about the study
During the course of this study, we may find more information that could be important to you. This includes information that, once learned, might cause you to change your mind about being in the study. We will notify you as soon as possible if such information becomes available.

You can get the answers to your questions, concerns, or complaints
If you have any questions, concerns or complaints about this study, or experience an adverse event or unanticipated problem, call Scott Lewis at 813-974-3099.

If you have questions about your rights as a participant in this study, general questions, or have complaints, concerns or issues you want to discuss with someone outside the research, call the USF IRB at (813) 974-5638.
Consent to Take Part in this Research Study
It is up to you to decide whether you want to take part in this study. If you want to take part, please sign the form, if the following statements are true.

I freely give my consent to take part in this study. I understand that by signing this form I am agreeing to take part in research. I have received a copy of this form to take with me.

__________________________   _______________________
Signature of Person Taking Part in Study               Date

_______________________________
Printed Name of Person Taking Part in Study

Statement of Person Obtaining Informed Consent
I have carefully explained to the person taking part in the study what he or she can expect from their participation. I hereby certify that when this person signs this form, to the best of my knowledge, he/ she understands:
  • What the study is about;
  • What procedures/interventions/investigational drugs or devices will be used;  
  • What the potential benefits might be; and  
  • What the known risks might be.

I can confirm that this research subject speaks the language that was used to explain this research and is receiving an informed consent form in the appropriate language. Additionally, this subject reads well enough to understand this document or, if not, this person is able to hear and understand when the form is read to him or her. This subject does not have a medical/psychological problem that would compromise comprehension and therefore makes it hard to understand what is being explained and can, therefore, give legally effective informed consent. This subject is not under any type of anesthesia or analgesic that may cloud their judgment or make it hard to understand what is being explained and, therefore, can be considered competent to give informed consent.

__________________________   _______________________
Signature of Person Obtaining Informed Consent / Research Authorization               Date

_______________________________
Printed Name of Person Obtaining Informed Consent / Research Authorization
2/4/2015

Li Ye, M.S.
USF CITRUS - Center for the Improvement of Teaching and Research in Undergraduate STEM Education
4202 East Fowler Ave., CHE205
Tampa, FL 33620

RE: Expedited Approval for Initial Review
IRB#: Pro00020840
Title: Investigating Evidence for the Validity of Chemistry Assessments Methods


Dear Ms. Ye:

On 2/4/2015, the Institutional Review Board (IRB) reviewed and APPROVED the above application and all documents outlined below.

Approved Item(s):
Protocol Document(s):
IRB Protocol.pdf

Consent/Assent Document(s)*:
Informed Consent B.docx.pdf

*Please use only the official IRB stamped informed consent/assent document(s) found under the "Attachments" tab. Please note, these consent/assent document(s) are only valid during the approval period indicated at the top of the form(s).

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB
may review research through the expedited review procedure authorized by 45CFR46.110 and 21 CFR 56.110. The research proposed in this study is categorized under the following expedited review category:

(6) Collection of data from voice, video, digital, or image recordings made for research purposes.

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

Kristen Salomon, Ph.D., Vice Chairperson
USF Institutional Review Board
Informed Consent to Participate in Research Involving Minimal Risk Information to Consider Before Taking Part in this Research Study
IRB Study # 00020840

You are being asked to take part in a research study. Research studies include only people who choose to take part. This document is called an informed consent form. Please read this information carefully and take your time making your decision. Ask the researcher or study staff to discuss this consent form with you, please ask him/her to explain any words or information you do not clearly understand. The nature of the study, risks, inconveniences, discomforts, and other important information about the study are listed below.

We are asking you to take part in a research study called:
Investigating Evidence for the Validity of Chemistry Assessment Methods
The person who is in charge of this research study is Li Ye. This person is called the Principal Investigator. However, other research staff may be involved and can act on behalf of the person in charge. She is being guided in this research by Dr. Scott Lewis.

The research will be conducted at the University of South Florida

Purpose of the study
The purpose of this study is to:

• Improve student performance in the science courses.
• A student is conducting this study for fulfillment of dissertation requirements.

Why are you being asked to take part?
We are asking you to take part in this research study because you completed General Chemistry I at the University of South Florida last term.

Study Procedures: What will happen during this study?
If you take part in this study, you will be asked to participate in an interview to last no longer than one hour. During this interview you will be presented with different formats of assessments designed for General Chemistry I. The interview will be audio recorded. You will be asked to complete each assessment to the best of your abilities and try to describe what you are considering while working on each assessment. You may be asked questions
during or immediately after each assessment technique to clarify what you describe while doing the assessments.

**Total Number of Participants**
About 12 individuals will take part in this study at USF.

**Alternatives / Voluntary Participation / Withdrawal**
You do not have to participate in this research study.

You should only take part in this study if you want to volunteer. You should not feel that there is any pressure to take part in the study. You are free to participate in this research or withdraw at any time. There will be no penalty or loss of benefits you are entitled to receive if you stop taking part in this study. The decision to participate or not to participate will not affect your student status (course grade).

**Benefits**
You will receive no benefit(s) by participating in this research study.

**Risks or Discomfort**
This research is considered to be minimal risk. That means that the risks associated with this study are the same as what you face every day. There are no known additional risks to those who take part in this study.

**Compensation**
You will be paid a $25 gift card if you complete the scheduled study visit. If you withdraw for any reason from the study before completion you will not be paid.

**Privacy and Confidentiality**
We will keep your study records private and confidential. Certain people may need to see your study records. By law, anyone who looks at your records must keep them completely confidential. The only people who will be allowed to see these records are:

- The research team, including the Principal Investigator, study coordinator, and all other research staff.

- Certain government and university people who need to know more about the study. For example, individuals who provide oversight on this study may need to look at your records. This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights and your safety.

- Any agency of the federal, state, or local government that regulates this research. This includes the Department of Health and Human Services (DHHS) and the Office for Human Research Protection (OHRP).

- The USF Institutional Review Board (IRB) and its related staff who have oversight responsibilities for this study, staff in the USF Office of Research and Innovation, USF Division of Research Integrity and Compliance, and other USF offices who oversee this research.

We may publish what we learn from this study. If we do, we will not include your name. We will not publish anything that would let people know who you are.

You can get the answers to your questions, concerns, or complaints
If you have any questions, concerns or complaints about this study, or experience an
unanticipated problem, contact Li Ye at liye@mail.usf.edu or 813-385-6475.

If you have questions about your rights as a participant in this study, general questions, or
have complaints, concerns or issues you want to discuss with someone outside the
research, call the USF IRB at (813) 974-5638.

Consent to Take Part in this Research Study
It is up to you to decide whether you want to take part in this study. If you want to take
part, please sign the form, if the following statements are true.

**I freely give my consent to take part in this study.** I understand that by signing this form
I am agreeing to take part in research. I have received a copy of this form to take with me.

________________________________________________________________________
Signature of Person Taking Part in Study                                      Date
________________________________________________________________________
Printed Name of Person Taking Part in Study

Statement of Person Obtaining Informed Consent
I have carefully explained to the person taking part in the study what he or she can expect
from their participation. I hereby certify that when this person signs this form, to the best
of my knowledge, he/ she understands:

- What the study is about;
- What procedures will be used;
- What the potential benefits might be; and · What the known risks might be.

I can confirm that this research subject speaks the language that was used to explain this
research and is receiving an informed consent form in the appropriate language.
Additionally, this subject reads well enough to understand this document or, if not, this
person is able to hear and understand when the form is read to him or her. This subject
does not have a medical/psychological problem that would compromise comprehension
and therefore make it hard to understand what is being explained and can, therefore, give
legally effective informed consent.

________________________________________________________________________
Signature of Person obtaining Informed Consent                                      Date
________________________________________________________________________
Printed Name of Person Obtaining Informed Consent

165
November 20, 2014

Li Ye, M.S.
Chemistry
4202 East Fowler Ave., CHE205
Tampa, FL 33620

RE: Expedited Approval for Initial Review
IRB#: Pro00019831
Title: Using Text Messages to Explore Students’ Learning Outside the Class

Study Approval Period: 11/20/2014 to 11/20/2015

Dear Ms. Ye:

On 11/20/2014, the Institutional Review Board (IRB) reviewed and APPROVED the above application and all documents outlined below.

Approved Item(s):
Protocol Document(s): IRB Protocol.docx

Consent/Assent Document(s)*:
Informed consent.docx.pdf

*Please use only the official IRB stamped informed consent/assent document(s) found under the “Attachments” tab. Please note, these consent/assent document(s) are only valid during the approval period indicated at the top of the form(s).

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review
procedure authorized by 45CFR46.110 and 21 CFR 56.110. The research proposed in this study is categorized under the following expedited review category:

(5) Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis).

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

John Schinka, Ph.D., Chairperson
USF Institutional Review Board
You are being asked to take part in a research study. Research studies include only people who choose to take part. This document is called an informed consent form. Please read this information carefully and take your time making your decision. Ask the researcher or study staff to discuss this consent form with you, please ask him/her to explain any words or information you do not clearly understand. We encourage you to talk with your family and friends before you decide to take part in this research study. The nature of the study, risks, inconveniences, discomforts, and other important information about the study are listed below.

We are asking you to take part in a research study called: Using Text Messages to Explore Students’ Learning Outside the Class
The person who is in charge of this research study is Li Ye. This person is called the Principal Investigator. However, other research staff may be involved and can act on behalf of the person in charge. She is being guided in this research by Dr. Scott Lewis.

The research will be conducted at the University of South Florida.

Purpose of the study
The purpose of this study is to:

- Improve student performance in the science courses.
- A student is conducting this study for fulfillment of dissertation requirements.

Study Procedures
If you take part in this study, you will be asked to complete a brief survey along with the informed consent. You will then receive text messages that ask if you have studied for this course in the past 48 hours and if so how. You will receive approximately two text messages per week and no more than three messages per week. The messages will be sent at random times between 9 AM and 9 PM. You will be asked to respond to each text message within 12 hours of receipt and can respond at any location. Please note: normal text messaging rates from your carrier may apply. Your responses may be considered in
the context of records already collected in the normal educational setting of your class, but no further actions are required of you beyond the survey and text message responses. Your instructor will be asked for your course records, namely test scores and course grade, after the completion of the semester.
Total Number of Participants

About 400 individuals will take part in this study at USF.

Benefits
The primary benefit is in knowing you contributed to how students learn outside the classroom in order to improve their learning.

Risks or Discomfort
This research is considered to be minimal risk. The only potential risk to the subjects is the unlikely event that the data collected will become accessible by an outside source. To minimize this risk, all data will be stored in a locked research laboratory and once data collection is complete, identifying information will be removed from the data and code words will be used. A third-party company will be used to send and receive the text messages. The third-party company has signed a confidentiality agreement. All data presentations will either be in aggregate (e.g. correlation values) or use pseudonyms.

Compensation
Participants who complete 80% of the requested text messages will be entered into a raffle for $25 gift cards. The odds for the raffle will be at least 5% depending on the number of participants who complete the project.

Privacy and Confidentiality
We will keep your telephone number and study records private and confidential. Certain people may need to see your study records. By law, anyone who looks at your records must keep them completely confidential. The only people who will be allowed to see these records are:

- The Principal Investigator and all other research staff.
- Certain government and university people who need to know more about the study. For example, individuals who provide oversight on this study may need to look at your records. This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights and your safety.
- Any agency of the federal, state, or local government that regulates this research. This includes the Department of Health and Human Services (DHHS) and the Office for Human Research Protection (OHRP).
- The USF Institutional Review Board (IRB) and its related staff who have oversight responsibilities for this study, staff in the USF Office of Research and Innovation, USF Division of Research Integrity and Compliance, and other USF offices who oversee this research.

We may publish what we learn from this study. If we do, we will not include your name. We will not publish anything that would let people know who you are.

Voluntary Participation / Withdrawal
You should only take part in this study if you want to volunteer. You should not feel that there is any pressure to take part in the study. You are free to decide to participate in this research or to withdraw at any time. There will be no penalty or loss of benefits that you are entitled to receive if you decide not to participate or to discontinue participation at any
time. Your decision will not affect your student status, course grade, recommendations, or access to future courses or training opportunities.

You can get the answers to your questions, concerns, or complaints. If you have any questions, concerns or complaints about this study, or experience an adverse event or unanticipated problem, contact Li Ye at liye@mail.usf.edu or 813-385-6475. If you have questions about your rights as a participant in this study, general questions, or have complaints, concerns or issues you want to discuss with someone outside the research, call the USF IRB at (813) 974-5638.

Consent to Take Part in this Research Study
It is up to you to decide whether you want to take part in this study. If you want to take part, please sign the form, if the following statements are true.

I freely give my consent to take part in this study and authorize that my instructor can provide my course records to the research team to aid this study. I understand that by signing this form I am agreeing to take part in research. I have received a copy of this form to take with me.

______________________________
Signature of Person Taking Part in Study

______________________________
Date

______________________________
Printed Name of Person Taking Part in Study

Statement of Person Obtaining Informed Consent
I have carefully explained to the person taking part in the study what he or she can expect from their participation. I hereby certify that when this person signs this form, to the best of my knowledge, he/ she understands:

• What the study is about;
• What procedures will be used;
• What the potential benefits might be; and
• What the known risks might be.

I can confirm that this research subject speaks the language that was used to explain this research and is receiving an informed consent form in the appropriate language. Additionally, this subject reads well enough to understand this document or, if not, this person is able to hear and understand when the form is read to him or her. This subject does not have a medical/psychological problem that would compromise comprehension and therefore makes it hard to understand what is being explained and can, therefore, give legally effective informed consent. This subject is not under any type of anesthesia or analgesic that may cloud their judgment or make it hard to understand what is being explained and, therefore, can be considered competent to give informed consent.

______________________________
Signature of Person Obtaining Informed Consent

______________________________
Date

______________________________
Printed Name of Person Obtaining Informed Consent
Appendix C: The Revised Two-factor Study Process Questionnaire

Please record your name, U-number and section number on the scan-tron. For items 1 through 20 please use the following scale to rate each item.
   A — this item is never or only rarely true of me
   B — this item is sometimes true of me
   C — this item is true of me about half the time
   D — this item is frequently true of me
   E — this item is always or almost always true of me

1. I find that at times studying gives me a feeling of deep personal satisfaction.
2. I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied.
3. My aim is to pass the course while doing as little work as possible.
4. I only study seriously what’s given out in class or in the course outlines.
5. I feel that virtually any topic can be highly interesting once I get into it.
6. I find most new topics interesting and often spend extra time trying to obtain more information about them.
7. I do not find my course very interesting so I keep my work to the minimum.
8. I learn some things by rote, going over and over them until I know them by heart even if I do not understand them.
9. I find that studying academic topics can at times be as exciting as a good novel or movie.
10. I test myself on important topics until I understand them completely.
11. I find I can get by in most assessments by memorising key sections rather than trying to understand them.
12. I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.
13. I work hard at my studies because I find the material interesting.
14. I spend a lot of my free time finding out more about interesting topics which have been discussed in different classes.
15. I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics.
16. I believe that lecturers shouldn’t expect students to spend significant amounts of time studying material everyone knows won’t be examined.
17. I come to most classes with questions in mind that I want answering.
18. I make a point of looking at most of the suggested readings that go with the lectures.
19. I see no point in learning material which is not likely to be in the examination.
20. I find the best way to pass examinations is to try to remember answers to likely questions.

* The responses to items are scored as follows:
  A= 1, B= 2, C= 3, D= 4, E= 5

* To obtain main scale scores add item scores as follows:
  Deep Approach = 1 + 2 + 5 + 6 + 9 + 10 + 13 + 14 + 17 + 18
  Surface Approach = 3 + 4 + 7 + 8 + 11 + 12 + 15 + 16 + 19 + 20

* This questionnaire was obtained from Biggs, J. B. (2001). The revised two-factor Study Process Questionnaire: R-SPQ-2F, British Journal of Educational Psychology, 71, 133-149.
Appendix D: Student Reasoning for Measure of Linked Concepts

Prompt: NaBr completely dissociates in methanol. (Boiling point of methanol = 64.6°C; K_b(methanol) = 2.7°C/m; density of methanol = .272 g/mL). For questions 1-9 indicate whether each statement is true (A) or false (B).

Statements:
1. Ion-dipole interactions are present in the solution.
2. The boiling point of the solution is 70.9°C.
3. Using PV=nRT, the pressure equals 0.215 atm.
4. The carbon in CH_3OH is sp^3 hybridized.
5. In the preferred Lewis structure of CH_3OH, oxygen has a formal charge of -1.
6. NaBr dissociates to form Na^{2+} and Br^{-}.
7. CH_3OH contains nonpolar bonds but is a polar molecule.
8. A bromine ion has a higher first ionization energy than a sodium ion.
9. ΔH_{solvent} arises from the hydrogen bonding between methanol molecules.
### Table 24. Summary of Student Reasoning for Measure of Linked Concepts (N=13)

#### 1. Ion-dipole interactions are present in the solution

<table>
<thead>
<tr>
<th>Answer</th>
<th>True (N=9)</th>
<th>False (N=1)</th>
<th>Not sure (N=3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasoning</td>
<td>NaBr dissociates to form Na⁺ and Br⁻ ions (3)</td>
<td>The b.p. given in the prompt is 64.6 deg C (2)</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>NaBr is ionic and the oxygen in methanol will have ion-dipole interactions with the solution (2)</td>
<td>Uses the b.p. elevation formula but inserts a mass value for m rather than molality (2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sodium is in group 1 and bromine is in group 7, thus it is dealing with ions (1)</td>
<td>The boiling point of the solution was not given in the prompt and is therefore unknown (1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interactions of metals and nonmetals (1)</td>
<td>Guessing (1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NaOH and CH₃Br will be formed (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dipole-dipole interactions are present because of Na (a metal); this is the same as ion-dipole (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summary note</td>
<td>Most students who correctly answered ‘true’ first determined that NaBr was ionic compound and would dissociate into ions that would interact with the polar methanol solvent.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 2. The boiling point of the solution is 70.9°C

<table>
<thead>
<tr>
<th>Answer</th>
<th>True (N=4)</th>
<th>False (N=6)</th>
<th>Not sure (N=3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasoning</td>
<td>The addition of NaBr should raise the boiling point (b.p.) of methanol (3)</td>
<td>The b.p. given in the prompt is 64.6 deg C (2)</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Guessing (1)</td>
<td>Uses the b.p. elevation formula but inserts a mass value for m rather than molality (2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The boiling point of the solution was not given in the prompt and is therefore unknown (1)</td>
<td></td>
</tr>
<tr>
<td>Summary note</td>
<td>None of the students correctly utilized the boiling point elevation formula to determine the b.p. of the solution. Those who selected ‘true’ either knew that the b.p. would at least increase or simply guessed.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 3. Using PV=nRT, the pressure equals 0.215 atm

<table>
<thead>
<tr>
<th>Answer</th>
<th>True (N=2)</th>
<th>False (N=10)</th>
<th>Not sure (N=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasoning</td>
<td>P = .215 (1)</td>
<td>PV=nRT is used for gases, so it is not applicable in this situation (4)</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Guessing (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P was calculated to equal a value other than .215 atm (i.e. 0.721 atm, 8.7 atm, 0.1 atm, 251.8 atm) (4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>PV=nRT is used for a gas solution and the prompt does not specify that this is a solution (1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>At STP, pressure equals 1 atm (1)</td>
<td></td>
</tr>
</tbody>
</table>
### Table 24. (Continued)

<table>
<thead>
<tr>
<th>Summary note</th>
<th>Four of the students who answered false correctly reasoned that the Ideal Gas Law would not be applicable in the given situation. An additional four who answered false attempted to utilize the formula and yielded results other than P=0.215 atm.</th>
</tr>
</thead>
</table>

| **4. The carbon in CH$_3$OH is sp$^3$ hybridized** |
|---|---|---|
| **Answer** | True | False | Not sure |
| **N=9** | **N=4** | **N=0** |
| **Reasoning** | Carbon makes four bonds (4) Carbon has four electron groups (2) Guessing (2) Of the three sp orbitals, one is filled and two are not (1) | Carbon is sp$^3$ hybridized (1) Carbon is sp$^3$ hybridized (1) Guessing (2) | N/A |

| **Summary note** | A majority of students attempted to find the answer by drawing a Lewis structure while a few tried to use orbital diagrams. |

| **5. In the preferred Lewis structure of CH$_3$OH, oxygen has a formal charge of -1** |
|---|---|---|
| **Answer** | True | False | Not sure |
| **N=1** | **N=11** | **N=0** |
| **Reasoning** | Guessing (1) | *Oxygen’s valence number is 6. You then subtract its number of non-bonding electrons (4) and the number of bonding electrons divided by two (4/2): 6 – 4 – 2 = 0 (7) Lewis structure appears stable so the formal charge of O is probably 0 (1) Oxygen forms two single bonds so its formal charge should be 0 (1) Guessing (2) | N/A |

| **Summary note** | Five of the students who answered ‘false’ correctly identified the formal charge using knowledge of valence electrons and determined that formal charge of oxygen is 0. *Several other students determined that the formal charge of oxygen was 0 but did not appear to have a firm grasp on why; instead they vaguely knew that they should subtract six from six without displaying mastery of the concept. |

| **6. NaBr dissociates to form Na$^{2+}$ and Br$^{-2}$** |
|---|---|---|
| **Answer** | True | False | Not sure |
| **N=2** | **N=11** | **N=0** |
| **Reasoning** | One ion is positive and one is negative (1) Guessing (1) | NaBr dissociates to form Na$^+$ and Br$^-$ (10) NaBr dissociates to form Na$^{3+}$ and Br$^{3-}$ (1) | N/A |

| **Summary note** | Ten of the eleven students who answered ‘false’ correctly identified that the ions would instead be Na$^+$ and Br$^-$. |
### 7. CH₃OH contains nonpolar bonds but is a polar molecule

<table>
<thead>
<tr>
<th>Answer</th>
<th>True</th>
<th>False</th>
<th>Not sure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=10</td>
<td>N=3</td>
<td>N=0</td>
</tr>
</tbody>
</table>

**Reasoning**
- C-H bonds are nonpolar but oxygen makes the molecule polar (6)
- Molecule will be overall polar because of its shape (1)
- Result of the number of bonds (1)
- OH is nonpolar but the molecule is polar because it is not balanced due to unequal forces (1)
- Guessing (1)
- A molecule cannot be polar if its bonds are nonpolar (1)
- A molecule cannot be both nonpolar and polar (1)
- The overall charge of the molecule is 0 so it is nonpolar (1)
- N/A

**Summary note**
Six of the ten students to correctly answer ‘true’ identified that the bonds created with oxygen caused the molecule to be polar, despite the presence of nonpolar C-H bonds. However, none of the students used the words “net” or “dipole.”

### 8. A bromine ion has a higher first ionization energy than a sodium ion

<table>
<thead>
<tr>
<th>Answer</th>
<th>True</th>
<th>False</th>
<th>Not sure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=8</td>
<td>N=5</td>
<td>N=0</td>
</tr>
</tbody>
</table>

**Reasoning**
- Ionization energy (IE) decreases down the periodic table, increases to the right (3)
- Sodium wants to lose an electron to have an octet like Ne. Bromine wants to gain an electron to have an octet like Kr. (1)
- Bromine more easily accepts an electron rather than giving one away (1)
- Sodium wants to lose electrons (1)
- Bromine is farther right than sodium on the periodic table (1)
- IE decreases to the right and increases down the periodic table (1)
- IE increases as you move up the periodic table (2)
- Sodium’s electrons are highly attracted to the protons so it is harder to take them away (1)
- Taking an electron from sodium requires a lot of energy, unlike for bromine (1)
- Guessing (1)
- N/A

**Summary note**
It appears that many students failed to treat bromine and sodium as ions, as described in the statement; instead many treated them as neutral atoms when reasoning through this statement. Many students also attempted to recall the direction of the trend on the periodic table rather than trying to reason using the definition of ionization energy. None of the students referred to electron or valence “shells.”

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Table 24. (Continued)

| 9. $\Delta H_{\text{solvent}}$ arises from the hydrogen bonding between methanol molecules |
|---|---|---|---|
| Answer | True | False | Not sure |
| N=5 | N=4 | N=4 |
| Reasoning | Guessing (3) Hydrogen bonding increases making it harder to break bonds, thus the energy required also increases (1) | Guessing (3) When NaBr is dissolved in methanol, hydrogen bonding is not the cause of the changing of $\Delta H$. (1) | N/A |
| Summary note | 10 out of the 13 students indicated that they were unsure of the answer or were simply guessing. |  |  |

*Numbers in () means the number of student used the reasoning*
## Appendix E: The Coding List for Interviews on Study Habits

### Study approaches

| Textbook | Use textbook  
|          | Only use textbook when not clear about certain concepts  
|          | Do questions in textbook  
|          | Do not use textbook  
| Notes/PPTs | Read/Review notes/PPTs  
| Practice problems | Do example problems  
|          | Do clicker questions outside the class  
|          | Do questions in the textbook  
| Flashcard | Use flashcard  
|          | Do not use flashcard  
| Old tests | Use old tests  
| Homework | Do homework  
|          | Do homework, but don’t review it afterwards  
|          | Save the homework on the test day  
|          | Use homework as self-quiz  
| Online resources | Use online resources (e.g. Google, Youtube)  
|          | Watch tutorials/videos  
| Attend class | Go through materials before lecture  
|          | Attend lectures  
|          | Take notes in the lectures  
|          | Attend Peer section  
|          | Record lectures  
| Office hours | Go to office hour  
|          | Bring unclear concepts to the professor or email  
|          | Went to professor’s review sessions in week of test  
|          | Would like to use teachers but intimidated  
|          | Visit professor on the test week  
| Group work | Study alone in high school  
|          | Study in groups in high school  
|          | Study alone in college  
|          | Study in groups in college  
|          | Study with peer/ friends in GC1  
|          | Study with peer leader  
|          | Tutor others  
|          | Depend on peers /peer leader  
|          | Get help from friends  
|          | Can help others, also get help from others  
|          | Do homework with friends  
|          | Ask friend about unclear concepts  
| Tutoring | Use tutor  

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## Metacognition / Evaluation of study approaches

| Helpful | Videos are helpful  
| Textbook is helpful  
| Notes/ PPTs are helpful  
| Practice problems is helpful  
| Homework is helpful  
| Professor is helpful  
| Peer leading is helpful  
| Group work is helpful  
| Flashcards are helpful  
| Old exams are helpful  
| Changed study approach is helpful |
| Not helpful | Peer section/ Team learning is not helpful  
| Text book is not helpful  
| Professor is not helpful  
| Clickers are not helpful  
| Homework is not helpful |
| Plan to change | Don’t have plan to change/ Didn’t change specific study techniques used  
| Would have studied differently/ earlier/ harder /more time  
| Would use textbook more  
| Would use outside sources or help  
| Would do less cramming  
| Would not rely on others  
| Would study with others  
| Has to prepare for weekly quiz now |
| Study more in college | Attend class more in college  
| Cover more materials in college  
| Practice more problems in college  
| Study consistently / Cramming less in college  
| Study more in GC2 |
| Independent learning | High school focus on student  
| Find own way in college  
| Try more independent learning |
| Keep doing helpful study approaches | Helping others has a huge influence on study habit so love it and keep doing it |
| Purpose of study | Study to get a basic knowledge |
| Text messages project | Positive  
| Test messages were helpful  
| Test messages gave reminder of study  
| Test messages lead to more study |
| Neutral | Test messages saw previous studying  
| Test messages spurred guilt over lack of studying |
| No Response | No response means didn’t study |
| Use text messages to monitor and improve | Texting study habits provided insight |

### Affective factors

| Attitude/Interest | Hate chemistry in HS  
|                  | Love chemistry in college  
|                  | Love specific chemistry topics  
|                  | Not a fan of chemistry  
|                  | Like to read about science subjects  
|                  | Follow chemistry stuff on Facebook  
|                  | Likes study for GC more than other classes  
|                  | Do not read about science subjects  
|                  | Read about science subjects sometimes |

| Confidence / Self-doubt | Not confident in chemistry  
|                         | Average confidence in chemistry  
|                         | More confident in GC2  
|                         | Just as confident in GC2  
|                         | Slightly less confident in GC2  
|                         | Bad at chemistry  
|                         | A slow learner  
|                         | Can’t learn chemistry by themselves |

| Satisfaction | Satisfied with the grade  
|             | Not very satisfied with the grade  
|             | I wish I had a better grade |

### Impression on chemistry

| Content | Not remembering content in previous courses  
|         | Chemistry is more math based / Not as conceptual  
|         | Chemistry is conceptual understanding  
|         | Chemistry is both math and conceptual  
|         | Chemistry is a list of separate facts  
|         | There is a theme in chemistry  
|         | Number of tests |

| Way of study | Study Chemistry involves memorizing information  
|             | Can’t memorize Chemistry, have to understand  
|             | Study Chemistry requires practice |

| Prior chemistry courses | 1 year of chemistry in high school  
|                         | More than 1 year of chemistry in high school  
|                         | Other chemistry course taken in college |
### Study environment

| Location | Study in the library  
|          | Study in my room  
|          | Study in pods  
|          | Study at a friends place  
|          | Study at work or in the office  
|          | Study in café or coffee place  |
| Sound   | Study in quiet environment  
|          | Study in quiet environment but not too quiet  
|          | Study while have music on  
|          | Study while have no music  |

### Other factors may affect performance

| Work | Work prevented studying  
|      | Work in other classes / Heavy course load prevented studying  |
| Content | Chemistry content prevented studying  
|      | Chemistry content never prevented studying  |
| Preparation | Lack of preparation for exams affect performance  |
| Other things | Change of instructor in the midway affect performance  
|      | Run out of time with other things prevent studying  
|      | Outside actions prevent studying  
|      | Ambiguous distraction prevent studying  |
Appendix F: The Complete Code List for Creative Exercises

CE codes

Black-correct  Blue-incorrect  Red-irrelevant

Values in brackets is number of students
Values in parenthesis are student code numbers

Gas Laws

Total number of students: 67

Reacting 1.45 L of 0.41 M of HBr with excess Calcium

\[
\text{Ca (s) + 2 HBr (aq) } \rightarrow \text{H}_2(g) + \text{CaBr}_2(aq)
\]

This reaction occurs at 1.61 atm and 45 degrees Celsius

Conversion

Total 43 students attempted to use this topic, 42 students used correctly, 1 student used incorrectly.

[42] 45 Celsius is 318.15 Kelvin (1, 4, 7, 8, 9, 10, 13, 16, 17, 18, 20, 21, 40, 50, 52, 86, 87, 88, 89, 90, 92, 93, 94, 95, 100, 101, 102, 106, 108, 110, 111, 113, 114, 115, 127, 132, 135, 136, 138, 140, 141, 142)

[2] 1.45L is 1450 mL (89, 90)

[1] Temperature is 318° K (6)

Compound

Total 10 students attempted to use this topic, 9 students used correctly, 3 students used incorrectly.

[6] CaBr₂ is an ionic compound or salt (1, 6, 106, 127, 132, 138)

[4] CaBr₂ is Calcium bromide, HBr is Hydrogen bromide (8, 50, 106, 138)

[1] Identifies cation or anion (95)

[2] HBr is an ionic compound or salt (1, 11)

[1] H₂ is called dihydrogen (106)

[2] H₂ is hydrogen or Ca is calcium (50, 106)

Stoichiometry


[25] Molecular mass of compound, CaBr₂ is 199.886 g/ mol, HBr is 80.912g/mol (2, 6, 8, 10, 11, 18, 50, 52, 86, 88, 90, 89, 93, 98, 100, 102, 105, 107, 111, 112, 127, 136, 138, 140, 142)
[23] 0.30 moles of H₂ gas, 0.30 moles of CaBr₂ or Ca (2, 12, 13, 17, 20, 51, 86, 91, 92, 94, 96, 104, 108, 111, 113, 114, 116, 132, 136, 138, 140, 141, 142)

[21] 12 grams of Ca, 48 g of HBr, 0.60 g of H₂ (1, 12, 18, 20, 51, 86, 89, 91, 92, 96, 101, 104, 112, 114, 132, 133, 135, 136, 138, 141, 142)

[1] Percent composition (11)

[18] 0.089 moles (8, 10, 16, 21, 40, 52, 87, 88, 89, 93, 94, 95, 96, 102, 108, 112, 113, 114)


[4] 11 moles from Ideal Gas Law (1, 92, 100, 106)

[3] 0.045 moles of H₂ or CaBr₂ (8, 21, 52)

[3] Molecular mass incorrect (92, 110, 128)

[1] 0.029725 moles of CaBr₂, H₂ (99)

[1] 1.189 moles of Ca (40)

[1] 0.036 moles of HBr (90)

[1] 0.63 mol of H₂ (105)

[1] Total moles are 0.6 (2)

[1] Mass of CaBr₂ wrong (89)

[1] It takes 2 moles of HBr to react with 1 mole of CaBr₂ (127)

Solution Chemistry

[14] Assign oxidation numbers or charges (1, 2, 6, 9, 11, 18, 93, 95, 97, 102, 109, 111, 127, 131)

[10] HBr is the limiting reagent (6, 17, 18, 21, 52, 101, 103, 106, 116, 138)

[9] CaBr₂ is soluble (1, 10, 17, 52, 98, 109, 113, 115, 127)

[9] Assign Ca as oxidized or H as reduced (1, 18, 92, 93, 97, 104, 109, 116, 13)

[7] HBr is an acid or strong acid (2, 50, 88, 108, 111, 115, 141)

[6] Assign H as oxidizing agent or Ca as reducing agent (1, 16, 92, 93, 104, 112)

[5] Single replacement or redox reaction (1, 7, 13, 94, 139)

[5] HBr is soluble (1, 6, 90, 109, 127)

[4] Ca is not limiting or excess (12, 17, 103, 108)

[2] Net Ionic equation Ca(s) +2H⁺(aq) = H₂(g) + Ca²⁺(aq) (1, 109)

[1] Molarity of H₂ is 0.0617 M (136)

[1] Identifies solubility rule that describes CaBr₂ is soluble (113)

[1] Ca is insoluble (93)

[1] Identifies Br⁻ as spectator ion (96)

[1] Identifies reactants and products (138)

[11] Incorrect ionic equation (1, 9, 10, 11, 13, 52, 94, 96, 109, 113, 133)
[7] Ca is the precipitate (10, 52, 88, 90, 94, 108, 141)
[4] Wrong charges (18, 102, 109, 111)
[3] Not a redox (9, 20, 115)
[3] Acid base reaction, at this point only Arrhenius theory has been presented (9, 99, 111)
[2] Br is reduced (4, 92)
[2] Molarity of H₂ is 0.205 (51, 113)
[2] H₂ is a precipitate (7, 91)
[2] Products or reaction are or is soluble (95,129)
[2] HBr is solvent Ca is solute (97, 141)
[2] HBr is oxidized or reducing agent (10, 106)
[1] Molarity is 0.061 (95)
[1] CaBr₂ is the precipitate (98)
[1] Double displacement reaction (127)
[1] Net ionic wrong equation (52)
[1] Reaction is not balanced (130)
[1] Ca is being reduced or oxidizing agent (106)
[1] CaBr₂ is the reducing agent (6)
[1] H₂ is the reducing agent (102)
[4] No precipitate (no solids) (9, 95, 116, 130)
[3] Equation is balanced (7, 129,136)
[2] Molecular equation as written (86, 139)
[1] Calcium would not be soluble with SO₄²⁻ (50)
[1] Not an acid base reaction (7)
[1] Reaction happens in water (50)
[1] Reaction will occur (13)

**Gas Law**

[3] H₂ is a gas (141, 50, 52)
[1] Density of H₂ is 0.12 g/L (136)
[1] Mole fraction of H₂ is 1.00 (17)
[1] Partial pressure of H₂ equals total pressure (17)
[22] Use 1.45 L in the ideal gas law (1, 8, 10, 16, 21, 40, 52, 87, 88, 92, 93, 94, 95, 97, 100, 102, 106, 108, 112, 113, 114, 115)
[14] Density incorrect (9, 10, 11, 18, 51, 52, 86, 88, 93, 106, 112, 116, 141, 142)
[6] State simple gas law relationships (17, 93, 95, 103, 112, 114)
[1] 4.832 L of CaBr₂ formed (140)
[1] Volume of HBr is 0.59 L (90)
[1] Volume of Ca is 1.45L (103)
[1] Temperature is 47.45 Kelvin (97)
[1] Partial pressure of H₂ is 0.48 (94)
[1] Identifies Br as gas (86)
[1] Rate of H₂ is slow since it has a low mass (17)
[1] Rate of H₂ is fast (142)

Miscellaneous
[1] Ca is a nonmetal (6)
[1] No bases (116)
[1] H₂ is diatomic (131)
[1] Ca is in column II (127)
Thermodynamics

Total number of students: 31

In the reaction, below 23.0 g of FeCl₂ undergoes the reaction in 5.15 L of water initially at 25.0 Celsius (assume 1.0 g/mL).

\[
\text{FeCl}_2(s) \rightarrow \text{Fe}^{2+}(aq) + 2 \text{Cl}^-(aq)
\]

\[
H_f(\text{FeCl}_2) = -341.8 \text{ kJ/mol} \quad H_f(\text{Fe}^{2+}) = -87.9 \text{ kJ/mol} \quad H_f(\text{Cl}^-) = -167.46 \text{ kJ/mol}
\]

Conversions

[7] 25.5 Celsius to 298.15 Kelvin (4, 7, 8, 17, 18, 127, 128)
[3] Conversion to 5150 g or 5.15 kg of water (1, 16, 20)
[2] 5.15L is 5150 mL (3, 8)

Atomic Structure

[1] Fe has 26 protons, 26 electrons, Cl has 17 protons, 26 electrons (8)

Compound

[2] Fe(II) is the cation, Cl⁻ is the anion (1, 18)
[2] Electrolytes are present (20,124)
[1] FeCl₂ is an ionic compound (4)
[1] FeCl₂ is Iron (II) chloride or ferrous chloride (3)
[1] Charge of Fe²⁺ is 2⁺ (1)
[1] Charge of Cl⁻ is 3⁻ (1)
[1] Aqueous solution has charged ions that flow free in the solution (16)

Stoichiometry

[13] 0.181 moles of FeCl₂ (1, 4, 13, 14, 17, 18, 19, 20, 21, 22, 123, 124, 128)
[12] 126.75 g/ mol molar mass of FeCl₂ (1, 2, 3, 4, 5, 6, 8, 12, 15, 17, 18, 124)
[7] 0.181 moles of Fe²⁺, 0.363 moles of Cl⁻ (1, 17, 19, 20, 21, 22, 124)
[3] FeCl₂ is 44.1% Fe by mass (or 55.9% Cl, or 10.1 g and 12.9 g) (4, 11, 21)
[2] 1.08 * 10^{23} atoms of FeCl₂ or molecules of FeCl₂ (1, 19)
[1] 0.181 L of FeCl₂ (11)
[1] 62.2076 moles of FeCl₂ (13)
[2] Molar mass of Fe or Cl (15, 18)
[1] One mole makes two moles (20)
[1] Reaction is balanced (7)

Solution Chemistry
[9] Dissolution or dissociation or decomposition reaction (2, 5, 6, 10, 12, 18, 124, 125, 129)
[8] FeCl₂ is soluble (3, 5, 14, 16, 20, 21, 127, 128)
[2] Molarity of FeCl₂ is 0.0352 M (18, 125)
[1] FeCl₂ dissolves (126)
[3] Molarity Wrong (14, 16, 126)
[2] FeCl₂ is a precipitate or solid that forms (7, 18)
[1] FeCl₂ is insoluble (1)
[2] Solution is an aqueous solution (16, 20)
[1] Solution is yellow (3)

Gas Laws
[4] Pressure from PV = nRT (4, 17, 18, 19)
[1] Simple gas law to find new volume (19)
[1] Density of water and temperature makes STP, so P = 1 atm (20)

Thermodynamics
[10] Exothermic reaction (1, 2, 6, 7, 14, 17, 125, 126, 127, 128)
[9] ΔH = -81.0 kJ/mol (4, 5, 14, 15, 17, 19, 124, 125, 128)
[2] 14.7 kJ energy released by reaction (12, 125)
[7] Amount of energy released wrong (or energy needed) (1, 6, 9, 10, 11, 14, 129)
[1] Change in temperature wrong, ΔT = -167.46 kJ/mol (7)
[4] ΔH = 81.02 kJ/mol (11, 12, 126, 129)
[4] Endothermic (10, 12, 123, 129)
[3] Amount of energy calculated from Q = mCT, where T is 25 °C (6, 7, 12)
[3] Solve for the energy of each component in the reaction (20, 22,128)
[1] 255 kJ/mol is given off in the product side (17)
[2] ΔH = -86.44 (2, 6)
[2] ΔH = 86.44 (9, 10)
[1] Reverse reaction is exothermic (11)
[1] Energy of products is 422.87 kJ/mol (126)
[1] Equation is an energy equation (16)
[1] FeCl₂ releases the most energy, Fe²⁺ releases the least (5)
[4] Specific heat of water is 4.186 J/g°C (5, 6, 7,127)
[1] At room temperature (3)
[1] Heats of formation are all exothermic (18)
[1] Specific heat is constant (16)

**Miscellaneous**
[1] Density of FeCl₂ is 3.16 g/mL (3)
[1] Density = 0.00447 g/mL (3)
[1] Cl⁻ has a density of 3.2g/L (11)
[1] Hydrogen bonds between water weaken (20)
Molecular Shapes
Total number of students: 31

\[ \text{COH}_2 \text{ where C is the central atom} \]
Electronegativity values: C = 2.5, H = 2.1 and O = 3.5

Atomic Structure
[1] Hydrogen has 1 electron, 1 proton (8)
[1] Oxygen has 16 electrons, 16 protons (8)

Compound
[1] Ionic compound (16)

Stoichiometry
[7] Molar mass of \text{COH}_2 \text{ is 30 g/mol (3, 6, 17, 41, 5, 58, 60)}
[1] Molar mass is incorrect (50)

Periodic Trends / Electron Configuration
[2] Electron configuration, H is 1s\(^1\), O is 1s\(^2\)2s\(^2\)2p\(^4\) (4,43)
[1] Oxygen has smallest ionization energy (52)
[1] Oxygen has largest electron affinity (52)
[3] Incorrect electron configuration (4, 43, 52)
[1] Oxygen has smallest atomic radius (52)

Lewis Structures
[21] Correct Lewis structure (1, 2, 4, 7, 36, 37, 38, 39, 40, 43, 13, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60)
[4] Molecule satisfies the octet rule (43, 13, 36, 54)
[4] O is the most electronegative (6, 5, 53, 57)
[3] C obeys the octet rule (1, 40, 55)
[3] C has zero lone pairs (3, 54, 55)
[3] Oxygen has two lone pairs (1, 53,57)
[3] 12 valence electrons (7, 10, 56)
[2] Harder to break double bond than single (4, 60)
[2] Calculate $\Delta$EN (39, 40)
[1] Oxygen has a full valence shell (5)
[1] Hydrogen one single bond (13)
[1] Oxygen has two bonds (13)
[1] CO is a double bond (57)
[1] The atom has 2 single bonds and 1 double bond (1)
[1] States two lone pairs (43)
[1] Calculates formal charges for each atom (51)
1. Formal charge is 0
2. C can have up to four bonds
3. COH$_2$ has four bonds
4. Total electrons are 16
5. Single line equals two electrons
6. Hydrogen only needs two valence electrons
7. O has an electronegativity that is greater than the H atom
8. Incorrect Lewis structure
9. The molecule contains 12 electrons
10. H is the most electronegative
11. Carbon has 6 valence electrons, oxygen 8, hydrogen 2
12. Oxygen has 9 valence electrons
13. One lone pair of electrons
14. Lewis Structure has no lone pairs
15. Carbon shares all its electrons
16. Oxygen only shares one pair of electrons
17. Attempts to share resonance by rotating molecule
18. Oxygen needs six bonds to complete octet
19. Carbon likes to be the central atom
20. C to O is a non-polar covalent bond and C to H is polar covalent bond
21. Polar bonds between each element
22. Since O is greater EN it pushes H’s closer together
23. There are no free radicals
24. No resonance

**Geometry/Shape**

1. Bond angle is 120°
2. Polar molecule
3. Draws trigonal planar
4. Electron geometry is trigonal planar or trigonal planar electron cloud arrangement
5. Molecular geometry is trigonal planar
6. Shape is trigonal planar
7. Three electron groups or three bonding sites
8. Physical geometry is trigonal planar
9. Tetrahedral electron geometry
10. Bond angle is 109°
11. COH$_2$ is nonpolar
12. Tetrahedral shape
13. Draws tetrahedral
14. Geometry is T-shaped
15. Shape is bent
Valence Bond Theory
[7] C to O has a sigma and pi bond present (C to H is a sigma bond) or tallying of sigma or pi (1, 37, 38, 40, 13, 51, 53)
[2] sp$^2$ hybridization (2, 40)
[1] The single bond is call a sigma bond (4)
[2] The double bond is called a pi bond (4, 53)
[1] Has 2sp orbital (38)
[1] Hydrogen bond is weak in s-orbital (50)
[1] Double bond in p-orbital (50)
[1] CO is sp$^2$, HC is sp (51)

Miscellaneous
[2] Hydrogen is a diatomic molecule (6, 5)
[1] Colorless gas (3)
Appendix G: MLCs Used as Homework Assignments

MLCs were developed for homework assignments using the Sapling Learning online homework system. Each MLC was incorporated as a single question within an assignment created in Sapling. The main purpose of the homework MLCs was to familiarize students with the assessment technique prior to seeing the technique on the high stakes in-class tests. Tables 25 to 28 below indicate the statements used within each homework MLC. Students were allowed up to ten attempts on each homework MLC and the values in each table reflect student performance on only their first attempt. The homework MLCs have considerably different administration techniques than in-class MLCs in terms of time limits, number of attempts and opportunity to work collaboratively. As a result, it is not recommended to compare student performance on the homework MLCs with student performance on the in-class MLCs presented in the article.

Table 25. HWMLC1

<table>
<thead>
<tr>
<th>Prompt: The quantum numbers n = 4 and l = 2</th>
<th>Percent correct</th>
<th>Correlation with Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Corresponds to a p-orbital (False)</td>
<td>85%</td>
<td>0.515</td>
</tr>
<tr>
<td>2 Can hold up to 4 electrons (False)</td>
<td>92%</td>
<td>0.354</td>
</tr>
<tr>
<td>3 ( m_l ) can only equal -1, 0, +1 (False)</td>
<td>89%</td>
<td>0.418</td>
</tr>
<tr>
<td>4 Has 5 orbitals (True)</td>
<td>65%</td>
<td>0.554</td>
</tr>
<tr>
<td>5 ( m_s ) can only equal ±½ (True)</td>
<td>78%</td>
<td>0.410</td>
</tr>
<tr>
<td>6 An electron with these quantum numbers could have an electron configuration of ([Kr] 5s^2 4d^3) (True)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>52%</td>
<td>0.615</td>
</tr>
<tr>
<td>7 An electron at these quantum numbers has more energy than an electron at ( n = 5, l = 0 ) (True)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>54%</td>
<td>0.536</td>
</tr>
<tr>
<td>8 When the last electron in the ground state has these quantum numbers, the atom is between Scandium and Zinc on the Periodic Table (False)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>63%</td>
<td>0.483</td>
</tr>
<tr>
<td>Total</td>
<td>82%</td>
<td></td>
</tr>
</tbody>
</table>

\( N = 1441 \)
### Table 26. HWMLC2

**Prompt: the molecule SF$_4$**

<table>
<thead>
<tr>
<th>Statements</th>
<th>Percent correct</th>
<th>Correlation with Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Molecule corresponds to the Lewis structure: :F:\</td>
<td>:F: :F: :F: :F:</td>
<td>93%</td>
</tr>
<tr>
<td>The name of the compound is sulfur tetrafluoride (True)</td>
<td>98%</td>
<td>0.314</td>
</tr>
<tr>
<td>0.150 moles of this compound would have a mass of 0.00139 grams (False)</td>
<td>91%</td>
<td>0.465</td>
</tr>
<tr>
<td>There are no σ or π bonds present (False)</td>
<td>97%</td>
<td>0.273</td>
</tr>
<tr>
<td>Its electron configuration is 1s$^2$ 2s$^2$ 2p$^6$ 3s$^2$ 3p$^6$ 4s$^2$ 3d$^{10}$ 4p$^1$ (False)</td>
<td>83%</td>
<td>0.547</td>
</tr>
<tr>
<td>In the preferred Lewis structure sulfur has a formal charge of +1 (False)</td>
<td>89%</td>
<td>0.511</td>
</tr>
<tr>
<td>The molecular geometry is see-saw (True)</td>
<td>90%</td>
<td>0.458</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>92%</strong></td>
<td></td>
</tr>
</tbody>
</table>

$N = 1280$

### Table 27. HWMLC3

**Prompt: 0.5945 moles of HBr react with excess Calcium in the chemical equation:**

\[
\text{Ca}(s) + 2 \text{HBr}(aq) \rightarrow \text{H}_2(g) + \text{CaBr}_2(aq)
\]

<table>
<thead>
<tr>
<th>Statements</th>
<th>Percent correct</th>
<th>Correlation with Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is a redox reaction (True)</td>
<td>59%</td>
<td>0.593</td>
</tr>
<tr>
<td>The volume of HBr is 9.64 L (False)</td>
<td>67%</td>
<td>0.489</td>
</tr>
<tr>
<td>CaBr$_2$ is calcium bromide (True)</td>
<td>93%</td>
<td>0.265</td>
</tr>
<tr>
<td>CaBr$_2$(aq) would have ion-dipole interactions present (True)</td>
<td>59%</td>
<td>0.603</td>
</tr>
<tr>
<td>The preferred Lewis structure for CaBr$_2$ is: [ \text{\textbf{\t}} \text{Br} - \text{\textbf{\t}} \text{Ca} - \text{\textbf{\t}} \text{Br} ] (False)</td>
<td>51%</td>
<td>0.642</td>
</tr>
<tr>
<td>HBr is the limiting reactant (True)</td>
<td>78%</td>
<td>0.476</td>
</tr>
<tr>
<td>Ca is a precipitate in this reaction (False)</td>
<td>80%</td>
<td>0.360</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>70%</strong></td>
<td></td>
</tr>
</tbody>
</table>

$N = 1220$
Table 28. HWMLC4

Prompt: A solution of $15.0 \text{ g PF}_3$ in $135 \text{ g H}_2\text{O}$. The solution has a volume of $145 \text{ mL}$ at $298 \text{ K}$, and the vapor pressure of water at this temperature is $23.8 \text{ torr}$.

<table>
<thead>
<tr>
<th>Statements</th>
<th>Percent correct</th>
<th>Correlation with Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  The solution has a higher boiling point than pure water (True)</td>
<td>72%</td>
<td>0.499</td>
</tr>
<tr>
<td>2  Hydrogen bonding occurs between PF$_3$ and water (True)</td>
<td>65%</td>
<td>0.635</td>
</tr>
<tr>
<td>3  PF$_3$ is phosphorous trifluoride (True)</td>
<td>95%</td>
<td>0.319</td>
</tr>
<tr>
<td>4  PF$_3$ is non-polar (False)</td>
<td>91%</td>
<td>0.452</td>
</tr>
<tr>
<td>5  The preferred Lewis structure for PF$_3$ is:</td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Lewis structure" /></td>
<td>91%</td>
<td>0.377</td>
</tr>
<tr>
<td>6  The total pressure is 1292 atm (False)</td>
<td>86%</td>
<td>0.462</td>
</tr>
<tr>
<td>7  The molality of the solution is 1.14 $m$ (False)</td>
<td>79%</td>
<td>0.558</td>
</tr>
<tr>
<td>8  The vapor pressure of the solution at 298 K is 23.3 torr (True)</td>
<td>63%</td>
<td>0.565</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>80%</strong></td>
<td></td>
</tr>
</tbody>
</table>

$N = 1176$
Appendix H: Interview Protocol for At-risk Students

1. Background questions
   - What is your major? Why did you take General Chemistry I?
   - What, if any, chemistry classes have you taken before General Chemistry I in college? In high school?
     - Why did you take these classes?
     - Are you satisfied with your performance in these classes?
     - How would you describe your performance in previous chemistry classes?
   - How would you characterize your study approaches?
     - Please describe any changes in how you study when transitioning from high school to college.
     - How important is studying with peers in high school versus studying with peers in college?
   - How confident are you in chemistry?
   - How satisfied are you with your resulting grade in General Chemistry I?
     - If you could return to when you were in General Chemistry I, would you do anything different in your studying for General Chemistry I? If yes, what would you do?
   - How is studying for chemistry different than studying for other classes?

2. Study habit text message clarification
   - To what extent did participating in the text message project influence your study approach?
   - If you did not respond to a text message, what was the reason?
   - Describe how you used [X] in your studying. X = the approaches the students indicated in their responses. e.g. textbook, homework, peer activity…
   - What study approaches did you think were helpful for General Chemistry I?
   - What study approaches did you think were not helpful for General Chemistry I?

3. External study habit questions
   - To what extent did the course instructor influence your study approach
     - Was there a particular way the teacher presented the material that you liked a lot?
     - Was there a particular way you did not like?
   - How many peers in chemistry do you interact with? How important are these interactions? Describe the nature of these interactions, what types of discussions do you have with your peers in chemistry.
   - What prevented you from studying for General Chemistry I?
     - What factors were outside of the chemistry content?
   - To what extent do you memorize content in General Chemistry I?
   - Would you characterize the content in General Chemistry I as having one or a small set of themes or as a list of separate facts?
   - How much of your studying for General Chemistry I was in practicing math examples versus conceptual understanding?
   - What did you do when you were not sure about a concept in your studying?
• Do you think you had too many tests or not enough tests in General Chemistry I?
• Do you read about science/chemistry beyond what is covered in the course?
• What was the most interesting thing you learned in General Chemistry I? Why was it interesting?
• How did your study approach change between General Chemistry I and General Chemistry II?
• How confident are you in learning General Chemistry II now?
• How are you getting ready for your upcoming General Chemistry II test?
• Where do you like to study?
• Describe your ideal study environment.
ABOUT THE AUTHOR

Li Ye got her Bachelor’s degree in Biotechnology in Huaqiao University, Fujian, China in 2008. She was recommended for admission to the Master program without taking entrance examinations in the Department of Chemical Engineering at the Huaqiao University. She got her Master Degree in Biochemical Engineering in 2011. Her master thesis was focus on development of novel drug delivery system containing drugs or cells. After that, she worked as a project manager in a biomedicine company for a year, managing projects associated with drugs used for nerve injury treatment. In 2014, She got admission and started her journey in the Ph. D. program in the Department of Chemistry at the University of South Florida, United States. Her research area is Chemistry Education, with an emphasis in exploring student learning in post-secondary General Chemistry. She got a verbal offer as a tenure track assistant professor in Chemistry Education at California State University, Northridge in August 2017.