Constructivist-Based Asynchronous Tutorial to Improve Transfer between Math and Chemistry Domains: Design, Implementation, and Analysis of the Impact of ReMATCH on General Chemistry Course Performance and Confidence

BY

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Constructivist-Based Asynchronous Tutorial to Improve Skill and Concept Transfer between Math and Chemistry Domains: Design, Implementation, and Analysis of the Impact of ReMATCH on General Chemistry Course Performance and Confidence

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Abstract

The two-year implementation of ReMATCH, a web-based math and problem-solving tutorial, in a traditionally arranged general chemistry classroom at the University of Kansas examined the impact of a designed intervention to assist students with the transfer of their mathematical knowledge to a chemistry context where it could be readily used for quantitative problem solving. The ReMATCH intervention, designed on constructivist-based pedagogies, focused on illuminating the expert-processes of problem solving and transferring knowledge across domains to the novice chemistry. The two implementations of ReMATCH – once as lab assignments and once lecture assignments – resulted in very different student responses to the intervention. However, within both, the beneficial effects of sustained ReMATCH-use were visible. In 2006, students who attempted all of the ReMATCH homework assignments were predicted to earn ~5% higher on their total exam points. The 2007 implementation of ReMATCH demonstrated that students who attempted all of the homework problems and visited at least half of the ReMATCH tutorial pages were predicted to earn ~8.5% higher on their total exam points.

Additionally, use of ReMATCH in 2006 also resulted in increased confidence (as measured by *comfort-level*) with some of the math-related chemistry topics covered in ReMATCH. In 2007, when only students who attempted all of the ReMATCH problems were considered, it became clear that individuals who were initially less confident in their math-related chemistry skills were more likely to view more of the ReMATCH tutorial pages. When students with lower initial comfort-levels on these topics viewed at least half of the ReMATCH tutorial pages, they were able to compensate for their initially lower levels of confidence and were equally comfortable with most of the math-related chemistry topics by the final survey. Student interactions with and perceptions of ReMATCH showed that student attitudes towards ReMATCH could be described by two factors: (1) how relevant and (2) how accessible they found the tutorial and homework to be. Students with more sustained interactions with ReMATCH presented more positive attitudes regarding the accessibility of the website in the 2006 study.

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Chapter 1

Introduction

> The student usually thinks of chemical arithmetic as some different kind of mathematics from anything he has ever heard of before. As a matter of fact the arithmetic of the calculations [in general chemistry] is the same kind he learned in the grammar school.
>
> …The chief function of problems in general chemistry is the illustration and application of principles. … The important part of the calculation is the thought used by the student in correctly applying the principle. … The teaching of multiplication and division is not one of the important functions of a course in chemistry.
>
> (Brinkley, 1925)

> It was the unanimous opinion that the class in general chemistry was sadly deficient in fundamental mathematical training, particularly in the use of decimals, percentage, and proportions. It was thought worth while to get some quantitative information as to the extent of the deficiency.
>
> (Jordy, 1925)

The impact of mathematics on the teaching of chemistry has been an active area of study since the American Chemical Society first established its Section of Chemical Education, later named the Division of Chemical Education. This is evident from the presence of two articles on the topic in the Division's *Journal of Chemical Education* during 1925, only its second year of publication. Published over 85 years ago, the authors of these early articles bemoaned their students' abilities to apply their mathematical knowledge to the subject of chemistry (Brinkley, 1925; Jordy, 1925). Little has evidently changed over the intervening period. A much more recent quote on this subject in the same journal provided the initial influence for the research presented here,

> Apparent shortcomings in students' mathematics and calculator skills in introductory chemistry can be described by two cases: an unlearned or missing skill, or the need for mathematics skills in chemistry that have gone unpracticed for one or two years. Most instructors do not want to spend time reviewing mathematics during chemistry lecture. This is particularly true in a large enrollment course in which an intervention for those in a bottom level would be boring and unproductive to the others in the class. This scenario lends itself to asynchronous instruction.
>
> (Pienta 2003)

Each of the prior observations were deemed consistent with observations of student performance in general chemistry at the University of Kansas (KU) in 2004 and 2005. Furthermore, it appeared that a significant portion of the KU students in general chemistry continued to struggle with the introductory math-related chemistry content near the end of the semester, including topics such as, conversion factors, significant figures, scientific notation, moles, molar mass, and stoichiometry. They struggled despite reviewing this material during the first two weeks of lecture. The students' focus on how to *do the math* and *what number to plug in where* appeared to be keeping many of them from attending to the chemical concepts that were the intended focus of the course. A literature review of how mathematical issues relate to student understanding and performance in chemistry generated an interest in providing an intervention for the general chemistry course to assist students with mastering this material earlier during the semester.

Literature Review of Mathematics in General Chemistry

The following initial question evolved from a preliminary review of the literature structured around Pienta's statement above: Were the general chemistry students, as Pienta suggested, having difficulty with the math-related chemistry topics because the course required math skills that were "unlearned" or "unpracticed" by the students? Many of the KU general chemistry students graduated from high school less than one year previously and enrolled in college algebra, pre-calculus, or calculus concurrently with general chemistry. As such, it is doubtful that these students lack recent opportunities to learn and apply the types of math skills that are necessary in a general chemistry course. The chemical- and science-education literature for the topics of conversion factors, significant figures, scientific notation, moles, molar mass, and stoichiometry does not provide an answer to why students with such recent connections to mathematics lack the appropriate skills to interact successfully with these primarily math-related topics in their chemistry courses. Instead, in many of the articles where these topics appear during the last thirty years, the authors simply state that students with various backgrounds both nationally and internationally struggle with these topics in chemistry (for examples see (Astudillo & Niaz, 1996; Bodner & McMillen, 1985; BouJaoude & Barakat, 2003; Dierks, 1981;

Friedel & Maloney, 1995; Heyworth, 1989, 1999; Ozsogomonyan, 1979; Phillips, 1989; Schmuckler, 1981). While it is reassuring to know that KU students are not alone in their struggle with this material, this knowledge cannot satisfy the need to address such deficiencies in the students' understandings of these essential topics early in the course.

A substantial portion of research relating mathematics and chemistry has focused on the predictive nature of math ability (as measured by math sub-scores on SAT or ACT exams) alone or in combination with demographic, prior academic performance, and cognitive ability variables on general chemistry performance (Andrews & Andrews, 1979; Bodner & et al., 1983; Bunce & Hutchinson, 1993; Carmichael, Bauer, Sevenair, Hunter, & Gambrell, 1986; Coley, 1973; Cornog & Stoddard, 1925, 1926; Craney & Armstrong, 1985; Figueroa, 1998; Mintzes, Sadler, & Tai, 2006; Ozsogomonyan & Loftus, 1979; Pickering, 1975; Schmuckler, 1981; Scofield, 1927; Spencer, 1996; Tai, Sadler, & Loehr, 2005; Tai, Ward, & Sadler, 2006). This supports the suggestion by Pienta (and many others) that math knowledge and ability play a significant role in student performance in general chemistry. Research along these lines has extended to the creation and use of many math-centered pre-assessments and diagnostic tests that are used by some colleges and universities to place students into an appropriate level of general chemistry at their institutions (Ager, 1993; J. S. Francisco, Marcella Trautmann, & Gayle Nicoll, 1998; Hovey & Krohn, 1958, 1963; Legg, Greenbowe, & Legg, 2001; McFate & Olmsted, 1999; Niedzielski & Walmsley, 1982; Pienta, 2003; Russell, 1994; Wagner, Sasser, & DiBiase, 2002). Research on the predictive ability of these placement and diagnostic tests has illustrated multiple times that while test score and course grade are related there is a much stronger correlation between test score and course success (passing the course with a grade of C or better) (Legg, et al., 2001; McFate & Olmsted, 1999).

In a number of universities, preparatory or remedial math/chemistry courses and self-paced remedial tutorials, ranging from a few weeks to a whole semester in length, have been created to accommodate the needs of any students missing high school chemistry or are underprepared for chemistry according to a diagnostic test (Bohning, 1982; Botch et al., 2007a; Gellene & Bentley, 2005; Jones & Gellene, 2005; Kogut, 1993; Krannich, Patick, & Pevear, 1977; Ozsogomonyan & Clinkscales, 1977; Walmsley, 1977b; Webster & Hooper, 1998). In a six-year study on the use of a remedial general chemistry course, Bentley and Gellene demonstrated that students who enrolled in the remediation did not subsequently earn a significantly different grade than those who needed remediation but did not seek it (Gellene & Bentley, 2005). At the time of this study, KU only had two general chemistry courses: regular ($N > 900$) and honors ($N < 40$, enrollment granted based on admission to KU honor program or an acceptable mathematics ACT or AP chemistry score). However, many of the students in the regular general chemistry course who appeared to struggle with the math-related chemistry topics had math backgrounds and standardized test scores that would predict their success in general chemistry, so some other factor(s) must have been involved.

Factors leading to students struggling with the math-related chemistry topics, even when the students have a sufficient mathematical background, can be attributed to a lack (or at least a lack of employing) the appropriate problem-solving skills. Much of the research regarding specific math-related chemistry topics focuses on the impact of students' proportional-reasoning abilities and higher-order cognitive abilities on students' success with these topics (Anamuah-Mensah, Erickson, & Gaskell, 1987; Bodner & McMillen, 1985; Gabel, 1981; Gabel & Sherwood, 1981, 1983a, 1984; Heyworth, 1989, 1999; Krajcik & Haney, 1987; Nurrenbern & Pickering, 1987; Vass, Schiller, & Nappi, 2000). Research in other science and social science fields have also focused on the influential nature of problem-solving skills and proportional reasoning ability on student performance, including tutorials to improve these ability in an undergraduate psychology course (Vass, et al., 2000) and physics course (Reif & et al., 1976; Reif & Heller, 1982a, 1982b). This research shows that many student problems with math-related chemistry topics stem from broader problems with applying proportional-reasoning and higher-order cognitive skills. According to these studies, students who use desirable cognitive strategies to a greater degree also perform better in general chemistry.

Other researchers have focused on improving student course performance in general chemistry by increasing students' algebraic math skills, conceptual understandings of the chemistry topics, or chemistry problem-solving skills. These studies have employed the following methods as attempts to improve student course performance, and they have met with various levels of success:

(1) tutorials, as either face-to-face workshops (Bohning, 1982; Kean, Middlecamp, & Scott, 1988; Nakhleh, Lowrey, & Mitchell, 1996) or computer-assisted instruction (Arasasingham, Taagepera, Potter, Martorell, & Lonjers, 2005; del R. Medina-Diaz, Echegaray, & Motta, 2000; Pienta, 2003; Pienta, Thorp, & Pano, 2001);

(2) graphical organizers (e.g. concept maps) (Arasasingham, et al., 2005; Gabel, 1986; Gabel & Sherwood, 1981, 1983b);

(3) analogies (Friedel & et al., 1990; Gabel, 1986; Gabel & Sherwood, 1980, 1981, 1983b); and

(4) heuristics or algorithms for problem solving (Beichl, 1986; Bodner, 1987; Bunce & Heikkinen, 1986; Frank & et al., 1987; Genyea, 1983; Kean, et al., 1988; Reif, 1983b).

Of particular interest among these studies was how the studies on heuristics and algorithms show that teaching these problem-solving techniques typically results in increased student success with obtaining correct answers, and, thus, improve performance in the course. However, these studies also show that despite improved performance students still lack sufficient conceptual understandings of the chemical problems they can solve (Nakhleh, et al., 1996; Phelps, 1996; Zoller & et al., 1995). Results from the concept mapping and analogy studies show that student conceptual understanding can be improved, but that these improvements do not necessarily result in enhanced performance on quantitative problem solving or better overall performance in the course. These discrepancies supported the observation that the KU students' mathematical abilities and conceptual understanding of chemistry were disconnected from their ability to successfully solve math-related chemistry problems. Therefore, though it seemed reasonable to assume that while some of the KU students were, as Pienta originally suggested, lacking the appropriate level of mathematical ability, another problem also existed: Other students were struggling because they lacked the ability to connect (transfer) mathematical representations to the chemistry concepts.

A Pressing Need for Action, but What Action?

Several additional questions arose from Pienta's 2003 quote: Was it true that the professor did not want to spend time on such a mathematical review? If so, was it for fear of boring a portion of the students in the course? Without being asked, the KU general chemistry professor confirmed Pienta's observations during a hallway conversation in the fall of 2005 when he mentioned that he was considering removing his lectures on the introductory math-related material from the course for the following year (Hierl, 2005). Since students were continuing to struggle with the material late into the semester despite his review of this material at the beginning of the course, he did not feel that the initial review was working for the students who needed it most. Additionally, the professor mentioned his concerns that the early focus on the math review in lecture might inadvertently lead some of the better students into a false sense of security early in the semester and result in their lack of attendance throughout the semester, ultimately negatively affecting their course performance. The decision to remove his lectures on the math-related chemistry material appeared logical since most students in the course had taken high school chemistry previously. A survey conducted near the time of this research confirmed that students who completed high school chemistry had covered this introductory math-related chemistry topics in their high school course (Deters, 2006). The survey examined the topics currently taught in first-year high school chemistry courses across all 50 states, and over 95% of the teachers surveyed reported teaching these math related topics of interest: moles/molar mass (98.4%), units/significant figures (98.4%), stoichiometry (95.3%), and dimensional analysis/factor label method (96.1%) (Deters, 2006). The KU professor felt that the few students without prior chemistry experiences and those students who felt that they needed a review of this material could use the review provided in the first four chapters of the text for the course (Chang, 2003).

While the previous method of teaching these topics was clearly not as effective as the professor would have liked, it seemed unlikely that students would understand and apply these topics more successfully when left to learn them on their own, without any direction on where to focus. Consequently, it was necessary to identify some methods of addressing students' deficiencies associated with the math-related topics outside of the lecture times and early in the semester. From a chemical education research perspective, the intervention chosen for this task had to (1) develop from sound theoretical framework, (2) use research-based practices, (3) fit the structure of the KU general chemistry course, and (4) address the specific needs of the KU students. The last two of these objectives were addressed first by identifying the needs and wishes of the stakeholders of the general chemistry course, the students and the professor. This information-gathering phase consisted of meeting several times with the general chemistry professor to discuss possible options for future semesters and administering a survey at the end of the semester to the general chemistry students. Then, another literature review, based on the stakeholders' preferences, was conducted to select an appropriate theoretical framework and to determine which research-based practices were most appropriate in the selected intervention.

Data Gathered from Stakeholders

During discussions with the professor, he displayed a great interest in meeting the needs of his wide range of students and a willingness to consider the incorporation of an asynchronous method of addressing the students' mathematical deficiencies in future semesters when the review of the introductory math-related topics would be removed from his lectures. He even offered to award five bonus points to each student who complete the survey in 2005 to encourage a greater level of student participation. Additionally, he agreed to accommodate any research examining the implementation and efficacy of the selected intervention in future sections of his course. Consequently, the flexibility of the course and its instructor were deemed suitable for the possible introduction of an intervention addressing these math-related chemistry concepts.

The multifaceted 2005 student survey was completed by 70% of the class during the last two weeks of the semester. Designed to

(1) ascertain whether the students believed that they were struggling with these topics,
(2) determine students' receptiveness to the idea of an asynchronous method to address math or problem-solving issues experienced during the course, and

(3) examine which aspects of the course lectures students found more interesting than others, the survey also requested information regarding the students previous math and science courses and demographic backgrounds to

(4) more fully describe the students being served by the general chemistry course.

Results from this survey, as well as course performance statistics and other academic and demographic variables from university records, are presented in detail in the Preliminary Research section of this document. A brief overview of these results is outlined below.

Based on the general chemistry students' responses to the survey, they appeared academically well prepared for the course: over 95% of the students had completed chemistry in high school, 50% had completed calculus in high school, and 73% had completed or were concurrently enrolled in calculus in college. In spite of this preparation, 22% of responders admitted to only occasionally or less frequently feeling comfortable with the concept of a mole in chemistry, and 29% could only occasionally or less frequently convert from the density to the moles of a compound. Nearly one-third to one-half of the students reported struggling occasionally or more frequently with the math-related chemistry topics of significant figures (35%), unit conversions (44%), mole fractions (45%), and stoichiometry (50%). Furthermore, over 65% of the students who reported occasionally or more frequently struggling with unit conversions and stoichiometry had already completed or were concurrently enrollment in calculus in college. Clearly, a large portion of the general chemistry students realized that they were struggling, at least occasionally, with the basic math-related chemistry topics, and struggling was perceived even by students with apparently sufficient chemistry and math backgrounds.

Based on the survey questions regarding possible interventions for this course, many more students expressed interest in possible web-based math (68%) and problem solving (80%) tutorials to accompany the course than were interested in personal math tutoring for this course (47%). Further comparisons showed that the group interested in the personal math tutoring consisted primarily of students at a math level below college calculus, while the groups interested in the web-based tutorials represented all mathematical backgrounds. The majority of the general chemistry students were evidently amenable to using some form of asynchronous method to address the math or problem-solving aspects of the course.

Other attitude questions on the survey asked about which portions of the course lectures students found most interesting. The percent of students agreeing that they were interested in the course lectures was much greater when the lectures covered chemistry concepts (82%) than when they focused on the math-related topics at the beginning of the semester (63%). Furthermore, significant portions of the students responding to this survey agreed that they would attend lectures more frequently if the lectures covered less math (30%) and more chemical theory (56%). These findings regarding student interest in lecture topics and changes to attendance patterns supported the previously mentioned suggestions by Pienta (2003) and the KU general chemistry professor that the math review at the beginning of the semester may be boring to many of the students. Other than the realization that two groups of chemistry students were struggling with the math-related chemistry topics for different reasons, (1) lower than necessary math-ability and (2) inability to transfer math skills, the remainder of Pienta's (2003) original quote fit the general chemistry situation to be addressed at KU very well. Therefore, the next step was to determine the pieces required for any asynchronous intervention to address both of these issues in the KU general chemistry course.

Necessary Aspects of the Intervention

Over two-thirds of the general chemistry students indicated an interest in having a web-based math or problem-solving tutorial to accompany the course. Consequently, to address the needs of the greatest number of the general chemistry students, any intervention provided for the students needed to address both aspects of the math-related chemistry topics where students felt they were struggling: (1) basic math skills and (2) problem solving (mainly, transfer). The intervention would have to provide both students needing a simpler math review access to material at their level and students struggling more with the application of mathematical principles to chemical problem solving the ability to move directly to tutorial materials more relevant to the context of chemistry. Identifying how such an intervention should function and what key strategies it should include required a return to the chemical education, science education, and cognitive psychology literature for an examination of the most appropriate theoretical frameworks and research-based practices addressing these issues. This review of the literature is provided in Chapter Two; however, a summary of this literature and how it informed the selection of an intervention follows.

Choosing a Theoretical Framework for the Intervention

The most abundant literature relevant to students' problems applying previously acquired math skills in their chemistry courses focuses on research about *skill and concept transfer* from one domain to another (Benander & Lightner, 2005) and the closely related research examining *implicit (or tacit)* versus *explicit* knowledge (Grossman, 2005) and *expert* versus *novice* problem solving (Heyworth, 1999). Each of these research areas presents strong ties to the theoretical framework of constructivism (Quintana, Zhang, & Krajcik, 2005). According to a constructivist framework, learners actively create their concepts based on prior knowledge and experiences; knowledge is not simply transmitted unchanged from teacher to learner as *behaviorism* would suggest (Bruner, 1961, 1997). The constructivist requirement that students must be actively involved in the creation of their knowledge presented a plausible reason for why many students in the KU general chemistry course struggled with the math-related chemistry topics after only *seeing* the topics presented in the early lectures. Therefore, constructivism was selected as an appropriate theoretical framework for the intervention that would be used to address students' difficulties with transferring their mathematical knowledge and skills to the chemistry context.

Based on this framework, only interventions incorporating research-based practices with strong underlying constructivist aspects were considered when selecting the specific intervention for use in the KU general chemistry course. Many of the constructivist-based methods previously linked to increases in student success with concept/skill transfer and problem solving can be described as methods of *learner-centered instruction* (Walczyk & Ramsey, 2003). The success of these methods stems from recognizing where students are in the process of problem solving and acknowledging that the previous experiences of different students have led to students with different prior knowledge. Even though not all of these successful constructivist methods explicitly state the influence of Vygotsky's Zones of Proximal Development, they each assist learners with moving from their current position in the problem-solving process to the next attainable level, a Vygotskian perspective (Palincsar, 1998). The following successful research-based constructivist practices were considered for inclusion in the general chemistry intervention: the *process-oriented approach to worked examples* (Crippen & Earl, 2004), *cognitive apprenticeship* (Dennen, 2004), *scaffolding* (Quintana, Krajcik, & Soloway, 2002; Quintana et al., 2004; Quintana, et al., 2005), the use of *analogies* (Orgill & Bodner, 2006), and *mastery learning* (Fountain & McGuire, 1994). Details of each practice are provided in the full literature review in Chapter Two.

As an extension of constructivism, research in the field of *social cognitive theory* has demonstrated the importance that a student's personal belief in his or her own ability to succeed at a task, referred to as the student's *self-efficacy* for the task, plays in the student's ultimate success or failure with the task (Bandura, 1989). The research on skill and concept transfer confirms the important role played by self-efficacy on the successful transfer of knowledge between domains and suggests several methods by which student self-efficacy can be increased for a particular task\(Bandura, 2000; Bandura, Barbaranelli, Caprara, & Pastorelli, 1996; Chiaburu & Marinova, 2005; Welch & West, 1995; Zusho, Pintrich, & Coppola, 2003). A visual representation of the theoretical framework informing the selection of the needed intervention is shown in Figure 1. This framework shows how concept and skill transfer are necessary for problem solving, displays the ever-present role of self-efficacy on learning and performance, and indicates that a number of methods have been linked to improved concept and skill transfer.

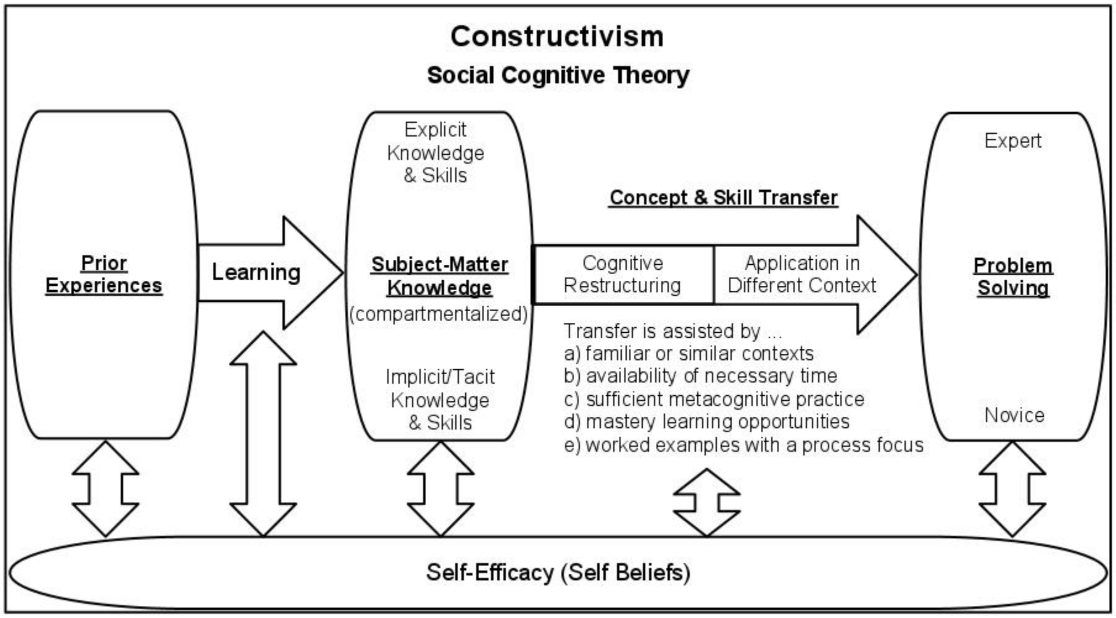

Figure 1 Pedagogical framework relating subject-knowledge, transfer, self-efficacy, and problem solving

Selecting an intervention

To determine if a previously created intervention met each of the requirements outlined above for use with the KU course, a review of the research literature was conducted to examine whether these research-based practices for increasing knowledge transfer between mathematics and chemistry had been successfully applied via asynchronous (outside of class time) methods in other courses. Despite the existence of several options for asynchronously addressing students' problems with the mathematically-related chemistry topics through the use of tutorials (via computer software, websites, or face-to-face out-of-class workshops) (Dori & Hameiri, 1998; Pienta, 2003; Pienta, et al., 2001; Suits & Lagowski, 1994; Wainwright, 1985) and review books (Appling & Richardson, 2003; Gabel, 1993), none of these options focused directly on assisting students with transferring their knowledge from one domain to a new domain, instead focusing on each domain independently. A number of classroom innovations have been created previously to focus on the transfer of skills or concepts across domains, but these usually occurred in preparatory or remedial courses taken by students prior to enrolling in a general chemistry course (Angel & LaLonde, 1998; Botch et al., 2007b; Gellene & Bentley, 2005; Krannich, et al., 1977; Meckstroth, 1974; Sherman & Sherman, 1976; Walmsley, 1977b; Wink, Gislason, Zusman, Mebane, & McNicholas, 2000), or they occurred during some portion of class time, either during lectures, labs, or discussion/recitation sessions (Herman et al., 2005; Kogut, 1993; C. H. Middlecamp & Nickel, 2005; Webster & Hooper, 1998). Therefore, it was necessary to create an asynchronous intervention focused on the transfer of skills between the math and chemistry domains to meet the needs of the KU students and course. This intervention, titled ReMATCH, consisted of a web-based tutorial and homework set incorporating research-based practices centered in a constructivist framework for student learning. Once ReMATCH was created to address the needs of all of the stakeholders, a design-based research methodology consisting of quantitative analyses supported by qualitative data was implemented to determine the effect of this asynchronous tutorial on student course performance and student confidence in their abilities to solve problems involving introductory math-related chemistry topics.

Overview of the ReMATCH Website

The ReMATCH tutorials consist of 88 content webpages covering the following topics: conversion factors, scientific notation, significant figures, rounding, converting metric units, the mole, molar mass, density, limiting reactants, theoretical yield, and molarity. Each of the math-related chemistry topics is introduced using the following sequence of steps:

(1) the topic was first introduced in several of its familiar everyday contexts (as its more familiar *analogs*),
(2) students were given multiple opportunities to walk through *process-oriented worked examples* (Crippen & Brooks, 2009; Crippen & Earl, 2004) and to practice these everyday uses of the mathematics on their own with *immediate feedback* regarding whether or not their solutions were correct (modeling expert processes and providing cognitive apprenticeship),

(3) the topic was then introduced in its chemistry context with comments explicitly made about how this new use follows the same pattern of application the students used in the everyday context (explicitly modeling transfer, highlighting the similarities of the two contexts), and
(4) students were given multiple opportunities to walk through process-oriented worked examples and to practice the chemistry uses of the mathematics on their own with feedback regarding whether or not their solutions were correct (modeling expert processes and providing cognitive apprenticeship).

This series of steps forming the basis of ReMATCH allows students' *self-efficacy* with particular mathematical tasks the opportunity to improve as the students work with the math in familiar contexts. The process also allows students to learn that the mathematics required for general chemistry includes skills with which they are already familiar but may never have examined critically before. The tutorial shows students how to write out the steps they normally perform implicitly (or tacitly) in an explicit manner that resembles how they will need to write out solutions to their quantitative chemistry problems – typically as a form of dimensional analysis. For the students who have previously performed these everyday tasks without thinking about why they are performed in a particular way, this initial introduction to the mathematical topic in the everyday context allows students to follow an expert's metacognitive explanation of why these everyday problems are solved the way they are (this provides students with the metacognitive exercise of analyzing why they address everyday problems they way that they do). Practice in modeling expert metacognitive schemas has been shown in previous research to improve students' use of expert schemas (Taconis, Ferguson-Hessler, & Broekkamp, 2001).

ReMATCH also includes a set of homework assignments consisting of a total of 40 problems (some with multiple parts) for students to complete during the first month of the course. While students are awarded points for completing the homework assignments, ReMATCH is based on a *mastery learning* approach to this material, and, therefore, students are provided immediate feedback regarding whether or not their answers are correct and allowed an unlimited number of attempts to answer each problem correctly. One goal of ReMATCH is for students to work on these assignments until they can answer each problem correctly. The asynchronous nature of the whole website and the unlimited number of attempts for each problem allows students the time they need for the *cognitive restructuring* of their prior knowledge, an essential step in the transfer of skills and concepts from familiar mathematical or everyday contexts to the chemical context (Bodner & McMillen, 1985).

A visual representation of how ReMATCH fits into the selected theoretical framework for the needed intervention is provided in Figure 2. ReMATCH provides an environment where students can gain assistance with the process of transferring mathematical abilities to the context of chemistry in the time that they require to gain mastery. This ReMATCH design framework describes the features incorporated to support the transfer of the students' implicit/tacit mathematical abilities to explicit abilities that they can perform in a chemistry context. Such transfer benefits from the modeling of desirable expert processes and schema (modeling expert metacognitive behaviors, such as understanding what questions to ask and recognizing the need to analyze common actions for their underlying concepts) and time to practice these expert models so that they can be incorporated into personal use (cognitive restructuring).

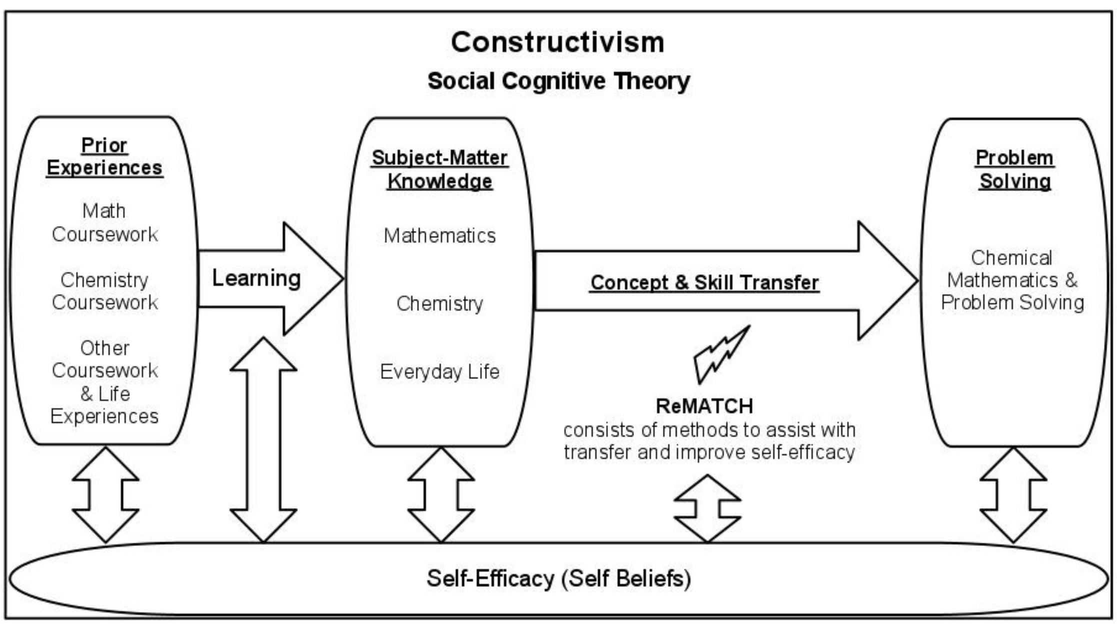

Figure 2 ReMATCH design framework.

Hypotheses

Preliminary exploratory research in 2005 examined how students' academic and demographic backgrounds related to their performance and experience in the first semester general chemistry course at KU (see Preliminary Study). Survey results revealed that students taking general chemistry during the fall of 2005 expressed a significant interest in having a math or problem-solving tutorial accompanying the course. This led to the development of the four-week web-based math tutorial titled ReMATCH: Reviewing Math – A Tutorial for Chemistry with Homework consisting of both math-related chemistry topics and problem-solving aspects. ReMATCH was designed as a website where students of varying math abilities could hone some of the basic math and problem-solving skills necessary for success in a general chemistry course. It provided students a structured asynchronous approach to learning this material, relating many of the math concepts to familiar tasks, providing many process-oriented worked examples, and giving students opportunities to practice applying their knowledge in an environment with immediate feedback and many scaffolded problems.

Created in the winter and spring of 2006, portions of ReMATCH were piloted with volunteers from the general chemistry course that same semester. Improvements to ReMATCH were made over the summer based on suggestions obtained from (1) interviews with pilot-study volunteers who used the tutorial website to varying degrees and (2) several subject matter experts who examined all of the website content[1]. In the fall of 2006, ReMATCH became a course requirement for an experimental group of general chemistry students, and the professor removed from his lectures most of the direct instruction on the initial math-related chemistry content from the first four chapters of the course textbook, *Chemistry* 8th ed (Chang, 2003). Because of these changes, students were expected to review this content outside of class using either the textbook or the ReMATCH website.

The structure and grading of the course in the fall of 2006 were similar to the course taught in the fall of 2005: three one-hour lectures per week and one three-hour lab per week combined for a total of 1000 points with 700 points from lecture (including three 100-point lecture exams, one 200-point

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[1] Special thanks is provided to April French, Kathryn Rebecchi, and Christina Munson for reviewing the ReMATCH tutorial and homework assignments and providing your expert suggestions and opinions.

final exam, and 200 possible homework points) and 300 points from lab. With the initial math-related chemistry content removed from the lectures in 2006 and made available through the ReMATCH website, the course accommodated a research study designed to examine the effects of students approaching this content via one of two asynchronous methods: (1) self-study or (2) ReMATCH tutorial assignments. Of particular interest in this research was the effect of each method on student course performance. This study also examined student confidence with the topics covered in the tutorial since the 2005 preliminary study showed that, at a time when the course lectures covered this material, many students reported that they struggled with the topics near the end of the semester. The research study in 2006 addressed the following hypotheses:

(1) Student course performance would differ significantly between students completing the ReMATCH assignments and students using the self-study approach.
(2) Student confidence with the math-related chemistry topics would differ significantly at the end of the semester between students completing the ReMATCH assignments and students using the self-study approach.
(3) Within the group of students assigned to use the ReMATCH tutorial, students who completed more of the assignments or spent more time on the assignments would report more positive attitudes towards the tutorial.

Enhancements made to the 2006-version of the ReMATCH website in the spring and summer of 2007 were based on (1) student responses to the fall 2006 survey questions about their interactions with ReMATCH and (2) email comments from 2006 users. Improvements made to ReMATCH that most affected tutorial users dealt with the length of each tutorial page, navigating between tutorial pages, and tracking each user's tutorial progress. These enhancements included (1) spreading long explanations of topics and instances of multiple examples for a single topic across multiple pages, (2) adding a more accessible method for users to jump between pages within a topic, and (3) providing users access to a table indicating which ReMATCH problems they previously answered correctly. After these updates, ReMATCH was used again in the general chemistry course in the fall of 2007, but this time completion of the ReMATCH assignments was a course requirement for *all* general chemistry students.

The course structure in the fall of 2007 was the same as in 2005 and 2006, but the grading-structure differed slightly. While the number of total points did not change, the professor added a fourth course-exam worth 100 points and allowed students to drop their lowest course-exam score from their grade calculation. The students still had homework assignments worth 200 points. However, the maximum points possible for completing the electronic homework was scaled down from 200 to 175, for the same number of problems, and students could earn the remaining 25 homework points by completing the ReMATCH assignments. Once again, the weekly laboratories and their point values, the textbook, the student resources for the course, and the prerequisites for the course did not change.

As in 2006, the instructor removed the initial math-related chemistry content from the lectures in the fall of 2007, and the material was accessible to the students through the textbook and the ReMATCH website. However, in 2007, all students were required to complete the ReMATCH assignments. Therefore, the focus of this research study was slightly altered; instead of focusing on comparing students who used ReMATCH as their approach to this material versus students who used a self-study approach, the research in 2007 focused on comparing students who viewed different numbers of ReMATCH tutorial pages while completing the tutorial assignments and on gaining a deeper understanding of how students interacted with and responded to the ReMATCH website. The research study conducted in 2007 addressed the following hypotheses:

(1) Student course performance would differ significantly between the groups of students using the ReMATCH tutorial at different levels.
(2) Student confidence with the math-related chemistry topics would differ significantly between the groups of students completing different amount of the tutorial assignments or viewing different amounts of the ReMATCH tutorial pages.
(3) Within the group of students who completed the ReMATCH assignments, students who viewed more of the ReMATCH tutorial pages would report more positive attitudes towards the tutorial.

Summary of Methodological Framework

While the pedagogical framework underlying the creation of ReMATCH was constructivism, answering the hypotheses from the 2006 and 2007 studies on the impact of ReMATCH-use for all users of the tutorial and identifying any differences between tutorial users and non-users required a different methodological framework. Methodologies based on a constructivist framework are mainly designed to elicit how students form their concepts and mental-representations by using qualitative methods, such as think-aloud protocols and concept mapping (Barak & Dori, 2005). Constructivist methods focus on identifying how a student's concepts change because of some intervention (Chiu, Chou, & Liu, 2002), but the constructivist methodological framework does not typically extend from this focus on conceptual understanding to the impact on overall performance in a course, especially in a course that does not test students using constructivist practices. The hypotheses of this research examine whether use of a web-based tutorial created on research-based constructivist practices and covering the initial math-related chemistry topics could improve student performance in the course and student confidence with this initial material. Constructivist methodologies have little concern for comparisons of student course performance or pre- and post-confidence; these comparisons require the use of quantitative methods.

A *design-based research* methodology informed the development, implementation, and analysis of the studies presented here because they included the development and analysis of an intervention in a classroom setting. Design-based research aims to bridge the gap between research and practice in education and requires three basic features: (1) an iterative nature, (2) the development of an artifact (intervention) to improve learning, and (3) the production of new knowledge about teaching and learning (Juuti & Lavonen, 2006). Design-based research commonly requires the use of multiple research methods to address the integration and effect of the artifact in the active classroom environment (Wang & Hannafin, 2005). Addressing the hypotheses for the 2006 and 2007 studies required the use of quantitative methods to determine the impact of ReMATCH-use on course performance, confidence with specific math-related chemistry topics, and attitudes towards ReMATCH.

Additionally, qualitative methods were necessary to obtain student insight about the design and function of the ReMATCH website. The qualitative data was useful for improving the tutorial and homework pages between iterations and for understanding what aspects of the tutorial students liked or disliked.

Design-based research is a branch of *design research*, a paradigm that "treats design as a strategy for developing and refining theories," instead of simply "as a way to implement theories for testing," (Edelson, 2002). Like design research, design-based research "emphasizes the process, the features of an artifact and educational knowledge development," but design-based research distinguishes itself by focusing on "long-term projects in single settings and compelling comparisons of innovations and collaborations about teachers and researchers" (Juuti & Lavonen, 2006). It is set apart from the more widely implemented methodology of *action-research* by its focus on the production of an artifact instead of a change in the actions of an instructor or classroom (Juuti & Lavonen, 2006), by its commitment to be theory-driven, and by its goal to be theory-extending (Bell, 2004; Edelson, 2002).

Design-based research gains many of its benefits from its theoretical framework of pragmatism. From this pragmatic view, design-based researchers see theory and practice as inseparable (Wang & Hannafin, 2005). In design-based research, the context and the intervention are considered together as the *enactment* of the artifact. In a design-based study, the analysis conducted is of the enactment, and not simply of the intervention in a context-free environment (Hoadley, 2004). Design-based research also emphasizes that there is much to be learned from the design process itself (Edelson, 2002). This requires the documentation of any changes made to the research design or intervention during the studies (Hoadley, 2004; Wang & Hannafin, 2005).

A note should be made regarding the underlying assumptions in the performance-related portions of these studies; it was assumed that (1) use of the tutorial would assist students with their transfer of math skills to the chemistry context, (2) ReMATCH-users would have an easier time mastering this material early in the semester, and (3) this would improve the ReMATCH-users' performance in the course. These assumptions were deemed reasonable based on a general belief in the current system of higher education – that a student's understanding of a topic is reflected in the student's ability to apply knowledge of the topic and that, therefore, performance on class exams reflects a student's level of understanding of the material in that class. While there are numerous examples of how students who perform well on traditional general chemistry exams do not necessarily understand the underlying concepts they are applying (Gabel & Bunce, 1994), no research studies have demonstrated that students who *do* understand the concepts perform poorly on traditional exams. Based on these principles, the studies presented here do not attempt to define any direct links between a student's ReMATCH-use and his or her conceptual understanding of the topics. However, since ReMATCH is designed on research-based constructivist practices that have been shown previously through constructivist methodologies to improve students' conceptual understanding, any difference in student performance that is linked to ReMATCH-use can be attributed (at least in part) to an improved conceptual understanding.

Structure of the Dissertation

The next three chapters expand on the creation of the ReMATCH website. Chapter Two delivers a full literature review of the pedagogical framework and research-based practices forming the basis for the creation of ReMATCH. Chapter Three provides the complete description and analysis of the preliminary study from the fall of 2005 in which the need is established for an intervention, such as ReMATCH, by KU general chemistry students from multiple academic backgrounds. Chapter Four describes the design of ReMATCH in detail, including the features it contains and the logistics of its use in the general chemistry course at KU.

Chapters Five through Ten focus on the 2006 and 2007 research studies conducted to determine the impact of ReMATCH-use on student course performance, confidence with the math-related chemistry topics, and attitude towards the tutorial. In Chapter Five the methods used to address each hypothesis are explained and a detailed description of the participants in each year of the study is provided. Chapter Six presents the results of analyses comparing the backgrounds of the different groups of students formed during various comparisons in the 2006 and 2007 studies and describes student use of ReMATCH and student course performance during both years. Correlations within and between sets of background variables and tutorial-use variables are also examined in this chapter.

Chapter Seven provides multiple linear regression analyses addressing the first hypothesis from each year of the study – the impact of ReMATCH use on course performance after controlling for any background variables. Chapter Eight describes the survey responses obtained each year while focusing on descriptions of student confidence with the math-related chemistry topics at the beginning and end of the semesters. Chapter Nine continues with the statistical analysis of the survey data by comparing student confidence and student use of ReMATCH to address the second hypothesis from each year of the study. Chapter Ten examines student attitudes towards and interactions with the ReMATCH website and describes the results of a factor analysis used to summarize student responses to ReMATCH. Then, this chapter addresses the third hypothesis from each year by comparing levels of student ReMATCH use to students' scores on these factors. Chapters Six through Ten all end with a discussion of the results from that chapter summarizing the work presented up to that point.

As the final chapter, Chapter Eleven outlines the conclusions drawn from this set of research studies and the implications that these studies make for teaching practices and future research. The 2005 survey along with combined versions of the initial and final surveys from the 2006 and 2007 studies are provided in the Appendices following Chapter Eleven.

Chapter 2

Literature Review

The initial section of this literature review provides an overview of constructivist theory focusing on the impact of personal and social constructivism on the development of pedagogies. Then, shifting the focus to chemical education, the role that constructivism has played in research on quantitative problem solving is explored.

In the second section, studies examining differences between experts and novices when problem solving are highlighted and the importance of skill and concept transfer to the problem-solving process is examined to illuminate why general chemistry students experience difficulties applying their mathematical skills and concepts when working chemistry problems. The lack of student recognition of the underlying principles held in their implicit/tacit skills and knowledge on the act of transfer becomes clear, and constructivist-based methods of turning implicit/tacit abilities into explicit knowledge are introduced. Finally, this section ends with a discussion of the impact of transfer on problem solving in chemistry.

In the third section, social cognitive theory is introduced and interactions between behaviors, personal attributes, and social environment are explored as they relate to learning. Then , the roles played by student attitude, self-confidence, and self-efficacy in problem solving and transfer are explored. The effects of the constructivist methods mentioned above on student self-confidence and self-efficacy are also highlighted as an introduction to the instructional strategy called guided mastery.

In the fourth section, the focus shifts from how constructivism and social cognitive theory research indicates that conceptual understanding, problem-solving, and skill/concept transfer is most beneficially addressed to the instructional strategies that have previously been applied in general chemistry classrooms to address students' quantitative problem-solving deficiencies. These methods include remedial and preparatory courses and tutorials, textbook reviews, mastery-learning approaches, and various asynchronous modules. From these, an attempt is made to identify a previously created intervention that would be appropriate for use in the KU general chemistry course, but none of the prior innovations match the needs of the KU course. Therefore, this section concludes with how the well-researched constructivist-based practices of familiar context, scaffolding, process-oriented worked examples, metacognitive skill training, analogies, and mastery learning are combined in a format very similar to guided mastery to inform the creation of ReMATCH, the web-based tutorial and homework site for use in the KU general chemistry course.

Constructivism

By emphasizing the impact of an individual learner's prior experiences and knowledge on his or her interpretation and mental-recording of new knowledge in formal or informal educational settings, constructivism has become a mainstay of educational research over the last half century. Pedagogies incorporating its theories have moved into math and science classrooms during the last thirty years. Constructivism is considered a reaction to the behaviorist-based theories of learning introduced by Edward Thorndike from the 1910s to the 1930s, popularized by B. F. Skinner in the mid-1950s, and commonly displayed in the programmed-instruction classrooms of the 1960s and 1970s (Bransford, Brown, & Cocking, 2000; Bruer, 1993b; Herron & Nurrenbern, 1999). Where behaviorists presented learning as a stimulus-response model—given the right stimulus in an educational setting, students should respond by learning the material as their teachers presented it—constructivists, such as Jean Piaget, Lev Vygotsky, Jerome Bruner, and Paul Cobb, presented learning as cognitive and social psychology models (Bransford, et al., 2000; Bruer, 1993b; Bruner, 1997; Herron & Nurrenbern, 1999). Constructivists shifted the focus of learning from the environment (the stimulus) to the individual student and stressed that knowledge is not imparted intact and unchanged from teacher to student; the student's unique background of experiences influences how the new information is approached and stored in the student's mind (Bodner, 1986; Cobb, 1994).

Personal (Cognitive) Constructivism

Different researchers associated with constructivism have identified various sources for the differing backgrounds and experiences of individuals. These range from the internal cognitive levels of development (personal constructivism) theorized by Jean Piaget to the sociocultural influences (social constructivism) that Vygotsky believed to be critical to what and how children learn (Bruner, 1997; Driver, Asoko, Leach, Mortimer, & Scott, 1994). Constructivism grew from the field of cognitive psychology thanks largely to the work of Jean Piaget from the late-1920s through the 1970s. Piaget's research on the cognitive development of children led him to the idea that children progress through different cognitive (reasoning) ability levels as they age: sensorimotor, preoperational, concrete operational, and formal operational (Bruer, 1993b; Karplus, 1977; Piaget, 1964). This progression of cognitive functioning explains why children understand experiences differently as they grow up. Piaget also formulated the idea that learning occurs for an individual when new knowledge presented to the person conflicts with his or her related prior knowledge or experience (Piaget, 1964). The individual must modify his or her prior understanding of concepts or events (must *accommodate* them) to incorporate (*assimilate*) the new information (Piaget, 1964; von Glasersfeld, 1974). This struggle between assimilation and accommodation must be an active concern – in a cognitive sense, it must be actively reflected upon – to promote meaningful learning; Piaget referred to this act of accommodating in order to assimilate new knowledge as *equilibration* (1964; von Glasersfeld, 1974). Over iterations of equilibration, cognitive schemes of categories of experiences commonly tied to specific contexts develop and are altered (Driver, et al., 1994; Piaget & Garcia, 1989). Based on these ideas, Driver and her colleagues described intellectual development as the "progressive adaptation of individual's cognitive schemes to the physical environment" (1994).

Social Constructivism

Another influential contributor to the field of constructivism was Lev Vygotsky. To the cognitive psychology theories of the 1920's that were focused mainly on the individual, Vygotsky introduced the impact that society has on an individual in his socio-historical context of development (sociocultural theory) (Bruner, 1997; Palincsar, 1998; Vygotsky, 1978). Bruner summarized Vygotsky's view of this relationship between individual and society as follows:

> Meaning making, in Vygotsky's view of the matter, requires not only language but a grasp of the cultural context in which *language is used*. Mental development consists of mastering higher order, culturally embodied symbolic structures, each of which may incorporate or even displace what existed before. … These higher order systems are cultural products. As instruments of the mind, they do not mature exclusively through endogenous principles of growth … but depend upon continued social interaction (Bruner, 1997).

As the individual *learns*, he or she is *internalizing* the surrounding socio-cultural norms to build upon the individual's prior knowledge (Cobb, 1994; Driver, et al., 1994). Since knowledge is first seen in society and then adopted in one's mental processes, social constructionism requires social interactions for a person to move beyond his or her current knowledge level. This idea leads directly into Vygotsky's most visible contribution to constructivist pedagogy: the *Zone of Proximal Development* (ZPD) (Bruner, 1997). In the ZPD, Vygotsky contributed to constructivism a theory linking the level of material that a student can learn unassisted to the level of material that a student can learn with the assistance of an adult or more advanced peer, a *knowledgeable other* (Bruner, 1997; Cobb, 1994).

Applying a Theory of Knowing to Instructional Practices

Personal and social constructivism, as developed by Piaget and Vygotsky, respectively, are theories of knowing; neither is a theory of teaching (Bransford, et al., 2000; Driver, et al., 1994; Richardson, 2003). As such, they make no claims about how, what, or when a teacher should teach. Effective uses of these theories in the classroom have developed from educational researchers and teachers who have used constructivist understandings of how learning occurs to develop pedagogies that support students during the personal and social process of coming to know and understand new material (Richardson, 2003). It is a common *mis*representation of the field that in constructivist-based instruction "teachers should never tell students anything directly but, instead should always allow them to construct knowledge for themselves" (Bransford, et al., 2000). This misrepresentation of constructivist-based pedagogies has led to most of the criticisms of these methods (Mayer, 2004).

Bruner: initial applications of constructivism to instructional practices.

Jerome Bruner applied Piaget's theory of developmental cognitive levels to the classroom when he developed his theory of instruction. According to Bruner (1963), a theory of instruction should include four features:

(1) create environment to predispose the learners to learn,

(2) structure knowledge to enable the learners to learn,

(3) sequence learning for the specific learners and goals of instruction, and

(4) select motivations and reinforcements considering the specific learners and goals of instruction.

Implicit in Bruner's descriptions of each of these features, and made explicit to constructivist-based pedagogies in general by later researchers, is that these features of instruction have two goals – (1) the students and (2) the desired learning outcomes; it is in relation to these goals that decisions about specific content and its presentation should be made (Bruner, 1963; Tobin & Tippins, 1993). Then, decisions can be made about which actions (i.e., structures, sequences, or motivations) will be necessary to assist the students with their assimilation of the new knowledge (Tobin & Tippins, 1993). Bruner was also responsible in the following decade for bringing Vygotsky's ZPD theory into the classroom through the pedagogical approach labeled *scaffolding* (D. Wood, Bruner, & Ross, 1976). This pedagogy provides a way in which children can be supported in a classroom setting to learn new knowledge just beyond their current level of understanding through the use of scaffolds, or gradually diminishing quantities of written or verbal expert assistance (D. Wood, et al., 1976).

Current applications of constructivism to instructional practices.

Due to the uniqueness of an individual's prior experiences, what each individual learns may or may not reflect what the teacher intended (Bransford, et al., 2000; Cobb, 1994). Therefore, one of the major influences that constructivism has had on current educational research and practice can be seen in the emphasis placed on determining the prior knowledge of students (through diagnostic tests or teacher-observed opportunities for students to engage with the general subject matter) before introducing students to what the teacher considers to be new knowledge (Hewson & Hewson, 1983).

Knowing what prior understandings students bring to their learning experiences allows teachers to have a better idea of how to introduce the new materials and what *alternative conceptions* need to be addressed along the way (Hewson & Hewson, 1983). This theory of accommodation and assimilation also supports the need for students to have some prior experiences with a general subject prior to being expected to learn it in a school environment. Without relevant prior experiences, students lack a basis into which the new knowledge can be appropriately assimilated; thus, the students are likely to associate the new knowledge with what they correctly or incorrectly believe to be their next closest experiences (Bransford, et al., 2000). To reduce the randomness of such associations created across a classroom of diverse students, many curricula based on constructivist theories suggest that students begin by having an opportunity in class or lab to explore a concept on their own in some active fashion (Driver, et al., 1994; Gabel, 2003; Richardson, 2003; Ryan & et al., 1980). This provides some common experience from which the community of leaners can begin to address new knowledge. To be effective in this goal, these initial experiences need to occur in a social structure and involve the learner in a dialogic process. Rosalind Driver, et al. (1994) applied this idea specifically to science learning:

> Learners need to be given access not only to physical experiences but also to the concepts and models of conventional science. The challenge lies in helping learners to appropriate these models for themselves, to appreciate their domains of applicability and, with in such domains, to be able to use them.

Constructivism also emphasizes that for learning to occur a person must make a mentally *active* attempt to reconcile their previous experiences or cognitive schemes with new experiences or knowledge (Bodner, 1986; Driver, et al., 1994). It is this active involvement in the creation of new knowledge by an individual that has become the most frequently identified aspect of constructivism. This emphasis on the need for opportunities for active learning (including experientially active learning initially and mentally active learning throughout) has led to many curricular reforms that focus on *inquiry learning* and *project/problem-based learning* (Barak & Dori, 2005; Gabel, 2003; Pedersen & Liu, 2002b; Quintana, et al., 2004; Savoy, 2006; Song, Grabowski, Koszalka, & Harkness, 2003). In both of these instructional strategies, students are provided “physical experiences that induce cognitive conflict and hence encourage learners to develop new knowledge schemes that are better adapted to experiences" (Driver, et al., 1994). The role of the teacher in these modes of instruction is very different from the familiar lecturer at the front of the room. However, for most constructivists, the role of the teacher is still essential to the classroom and to the creation of new knowledge because students need to be supported and guided through their inquiries, projects, or problems and encouraged to reflect on their experiences (Bodner, 1986; Bransford, et al., 2000; Driver, et al., 1994).

Most critics of constructivist pedagogies continue to espouse a misrepresentation of these strategies in which teachers serve a greatly diminished role and all constructivist pedagogies are lumped together with those that are most commonly labeled as *discovery learning* or *nature learning* (Driver, et al., 1994; Mayer, 2004). This misrepresentation has been labeled the "constructivist teaching fallacy" (Mayer, 2004).While discovery learning was suggested by constructivists for a short period of time as a possibly beneficial pedagogy (Bruner, 1961), it has now been shown to be far less effective than more *guided inquiry* pedagogical options and has therefore been dropped as a suggested practice by the vast majority of constructivists (Mayer, 2004; Suits & Lagowski, 1994). The necessity of some level of guidance while students construct their own understandings of experiences emphasizes the relevance of social constructivism to effective educational strategies. While being sure to emphasize that all students should initially be provided relevant experiences when beginning to learn new material (a personal constructivist perspective), many constructivists agree that after such initial opportunities short lectures introducing context- or domain-specific terms and general accepted explanations commonly have a role in a constructivist classroom, especially when it leads into a group discussion of the phenomenon being examined (a social constructivist perspective) (Bransford, et al., 2000; Driver, et al., 1994; Richardson, 2003).

Because of the focus on the individual learner that constructivism promotes, many of its pedagogical manifestations are referred to as *learner-centered approaches to teaching* as opposed to the *teacher-centered approaches* formerly favored in classrooms and still visible today in many classrooms. According to Walczyk and Ramsey (2003), learner-centered instruction facilitates students in the construction of knowledge by considering their interests, backgrounds, and development through the incorporation of six principles outlined in the National Research Council's book *How People Learn:*

Brain, Mind, Experience, and School (1999). These six principles conceptualize learning from a constructivist perspective

> (a) Students must perceive that the material to be learned is important.
> (b) Students must act on the information in some way at a deep level.
> (c) It is crucial that they relate new material to information they already know.
> (d) Students must continually check and update their understandings based on new experiences.
> (e) New learning does not automatically transfer to new contexts to which it is relevant.
> (f) Finally, students become autonomous learners if they become aware of the process of learning itself, including strategies for consolidating new material and for checking their understanding (Uno, 1999)
>
> (Walczyk & Ramsey, 2003)

Most learner-centered pedagogies focus on engaging students in their learning process. Often the student is aware that the design of the learning in the course is for them, not necessarily the faculty's benefit (Quintana, et al., 2002). Additionally, it is common for learner-centered instruction to focus more on mastery goals (working to develop competency with a concept or skill) rather than performance goals (memorizing to get an A on the test) (Meece, Herman, & McCombs, 2003). Several strategies involve short web-based homework assignments related to the next or previous course lecture to be completed just before entering the lecture course (referred to as Just in Time Teaching, JiTT) and courses structured around frequent quizzes, possibly at every class meeting to motivate students to study throughout the semester (Slunt & Giancarlo, 2004). A number of learner-centered pedagogies involve computer or web-based interfaces to support student learning with scaffolded aids (Quintana, et al., 2002; Quintana, et al., 2004; Quintana, et al., 2005).

Deciding Between Constructivist Pedagogies: Personal, Social, or Both

While Bruner incorporated both personal and social constructivist theories into pedagogy through his different instructional strategies over the years, he made it clear in his 1997 article, aptly titled, "Celebrating Divergences: Piaget and Vygotsky," that he did not advocate for the combination of Piaget and Vygotsky's separate fields of constructivism "in the hope of explaining both extremes of this astonishing human variability." He believed that the separate theories benefited from their different world views and pedagogical strategies and "that the two approaches constitute two principled, incommensurate ways by which human beings make sense of the world:" Piaget's focus on "*causal explanation* and its *logical and empirical justification*" and Vygotsky's focus on "*interpretation* and *understanding*" (Bruner, 1997). Despite his push for their continued separation as theories of knowing, Bruner made no mention of whether he supported the concurrent use of pedagogies developed from these two divergent fields of constructivism. As theories of learning, he sees them as balancing each other by their separate existences, so it follows that he would view the concurrent presence (in a single classroom) of pedagogies arising from each field as a method to ensure a balanced approach to student learning.

In contrast to Bruner's focus on the different origins and goals of Piaget's and Vygotsky's extremes of constructivism, Paul Cobb (1994) focused on highlighting how the personal (or cognitive) and social fields of constructivism each support the other in his comparison of pedagogies for mathematical education that have developed independently from each of these fields. Cobb concludes that when referring to pedagogy – when looking for what will help the students learn – adhering to a single world-view (personal or social) fails to acknowledge fully the process of meaning making for the student. Cobb, therefore, supports a pragmatic approach to these theories as they apply to instruction, and he suggests that researchers and teachers should "consider what various perspectives might have to offer relative to the problems or issues at hand" (1994). A very similar view has also been taken by other educational researchers (Driver, et al., 1994; Tobin & Tippins, 1993). Tobin and Tippins (1993) describe this view when they state that "knowledge is personally constructed but socially mediated." They extend this belief to support the idea that effective pedagogies should account for both views:

> The recognition that knowledge has both individual and social components that cannot be meaningfully separated enables us to construct science learning environments where multiple ways of knowing … are sought and valued (Tobin and Tippins, 1993).

It is this pragmatic view of constructivism as applied to pedagogies that this research project adopted as the pedagogical framework for the instructional intervention needed in the general chemistry course at KU. The design and implementation of the math tutorial intervention needed to support both the personal cognitive development of each student and his or her enculturation regarding the use of math in a chemistry context.

Constructivist-Based Pedagogies in Science Classrooms

Focused on Problem Solving

Ideas from constructivism have influenced individual teachers and researchers across math and science fields as the different theories of constructivism initially developed. George Bodner's article in 1986 on the theory of constructivism and its role in learning and doing science in the Journal of Chemical Education brought constructivism to the masses of chemistry educators. However, wide sweeping movement toward constructivist-based pedagogical practices in science and math classrooms did not occur until the 1990s (Gabel, 1999b; National Science Foundation, 1996). As constructivist theories of learning have led to constructivist pedagogies in math and science classrooms, a major theme for research and curricular reform has arisen around the role that constructivism and constructivist-based pedagogies play in explaining student difficulties (and successes) with *problem solving* (Gabel, 1999b). In the *Handbook of Research on Science Teaching and Learning* (1994), Dorothy Gabel and Diane Bunce contributed a whole chapter entitled, "Research on Problem Solving: Chemistry." Their review of problem solving research focused solely on studies in which a constructivist model of learning was applied "exclusively [to] chemistry problems involving mathematical reasoning skills that students have difficulty solving" (1994). These types of homework problems are typically associated with traditional undergraduate general chemistry courses. It is well documented that students struggle with these types of problems and that many students who are able to solve these problems correctly do so by using algorithms and do not necessarily understand the conceptual aspects of the problem (Bodner & McMillen, 1985; Gabel, 1986; Gilbert, 1980; Nakhleh, et al., 1996; Nurrenbern & Pickering, 1987).

Experts Versus Novices

In 1992, Patricia Alexander summarized what domain knowledge meant to problem-solving researchers by stating that within a particular field of study domain knowledge "encompasses declarative (knowing that), procedural (knowing how), and conditional (knowing when and where) knowledge … and can operate at a tacit or explicit level." With their interest in how students construct new knowledge, constructivist researchers have addressed students' lack of conceptual understanding by studying what the conceptual understanding of the domain looks like in *experts* (individuals in whom the knowledge of a domain is well established) and comparing this to the conceptual understanding in *novices* (those with limited domain knowledge) (Alexander, 1992; Alexander & Judy, 1988; Heyworth, 1989, 1999; Reif, 1982). In these studies, researchers have typically observed experts and novices solving science or math problems while using think-aloud protocols or concept-mapping that require the experts and novices to explain the processes they use and connections they access when solving specific types of problems (Alexander & Judy, 1988; Bunce, Gabel, & Samuel, 1991; J. S. Francisco, Nakhleh, Nurrenbern, & Miller, 2002; Gabel, 1981; Larkin, 1979; Larkin & Reif, 1979; Lorenzo, 2005; Nakhleh & Krajcik, 1991; Reif, 1982; Zhang, Liu, & Krajcik, 2006). Studies like these in physics have demonstrated that experts "redescribe problems presented to them" and spend a significant amount of time planning solutions prior to using any formulas; by contrast, novices "fail to describe problems adequately," spend minimal time planning, and instead attempt "to assemble solutions by stringing together miscellaneous mathematical formulas from their repertoire" (Reif & Heller, 1982b). Another important point that came to light from these investigations into expert problem solving included that the processes and connections mentioned by experts in their interviews and concept maps were far more complex and complete than those that instructors typically shared with students when working through problems in lectures (Gabel, 1999a; Grossman, 2005; Kramers-Pals & Pilot, 1988). Additionally, any cognitive restructuring of the expert's knowledge that was necessary when new knowledge was introduced was not shared with the students (Bodner & McMillen, 1985, 1986; Suits, 2000).

In attempting to solve problems, the novices typically only modeled the processes and connections that their instructors made explicit during lecture, resulting in an approach that was often very algorithmic in nature (Gabel & Bunce, 1994; Gilbert, 1980). The processes and connections not employed by students were usually the ones that the instructor held implicitly or tacitly and related to the types of questions the instructor asked of himself while progressing through the problem and how the teacher transforms (restructures) a nonstandard problem into a standard problem (Bodner & McMillen, 1986; Grossman, 2005; Kramers-Pals, Lambrechts, & Wolff, 1982; Reif, 1982; Richetti & Sheerin, 1999). The instructor's reflection on the knowledge he or she holds is not made clear to the students. In their summary of 15 years of research on the expert-novice paradigm in chemical education, Gabel and Bunce (1994) outlined three suggestions for assisting novices with their transition to become more expert-like:

(1) "increasing the underlying conceptual understanding of novices,"
(2) "making explicit the actual steps taken by experts to solve problems, and"
(3) "helping construct explicit relationships among the chemical principles, laboratory investigations, and mathematical applications for a given topic."

Therefore, one suggestion that comes from constructivist research regarding improving student learning involves instructors being much more explicit about their processes and schema employed when working examples in class, especially in regards to the types of questions they ask themselves while solving problems (Bunce & Heikkinen, 1986; Grossman, 2005; Heyworth, 1999; Kennedy-Justice et al., 2000; Reif, 1982; Reif & Heller, 1982b; Richetti & Sheerin, 1999; Rickey & Stacy, 2000). In terms of constructivism, the instructors need to show the students how to engage actively with their own knowledge creation. Teaching students *metacognition* skills, or how to be actively engaged in thinking about what they know, has been shown to improve student learning (Alexander & Judy, 1988; Rickey & Stacy, 2000; Song, Grabowski, Koszalka, & Harkness, 2006). Studies teaching students to analyze an activity that they normally perform "mindlessly" (or, implicitly) have found that when tasks were analyzed student performance improved and students were "able to apply the same learning to entirely new situations" (Salomon & Perkins, 1989). One instructional strategy, called *cognitive apprenticeship*, addresses this issue by having experts model their processes when solving a problem (Dennen, 2004; Pedersen & Liu, 2002a). Students can also be encouraged to actively engage in their problem-solving process when an instructor is not present through the provision of adequate scaffolding in homework problems or through the use of *process-oriented worked examples* (Crippen & Earl, 2004; Pedersen & Liu, 2001, 2002a; Song, et al., 2003; Stiff, 1988).

Another observation from these studies is that knowledge in novices is much more compartmentalized than knowledge is in experts. This compartmentalization of knowledge versus the many connections between knowledge in different domains that are present in expert schema provides one explanation for why novices are less likely to transfer knowledge from one domain to another (Benander & Lightner, 2005; Vass, et al., 2000). Findings related to this issue have led to the suggestion of using multiple familiar and new scenarios when introducing new information can increase the number of connections that students form between it and their prior cognitive schemas. This process improves student concept learning and problem solving by increasing the likelihood that the new information will be retrieved when it is required (Halpern & Hakel, 2003; Pence, Workman, & Haruta, 2005; Phelps, 1996). Students need to recognize several domains to which their new knowledge applies, and they need to know the limits of their new knowledge, where it does not apply (VanderStoep & Seifert, 1993). Learning the applications of concepts while learning the concepts themselves has been linked to students having an increased level of success with selecting correct procedure for problem solving (VanderStoep & Seifert, 1993). The *Chemistry in Context* textbook initiative of the American Chemical Society, intended for a non-majors general chemistry course, attempted to provide these connections (Schwartz et al., 1994). Another attempt to provide students with opportunities to apply new knowledge to multiple domains is seen in the *project-based learning* or *problem-based learning* curricula that have developed by Barak & Dori (2005), Lawson (1985), Savoy (2006), and Song, et al.(2006). In 2005, Barak and Dori found that students in an information-technology rich project-based learning environment were able to transfer their knowledge more easily and had a better understanding of chemical concepts and theories. The use of analogs and analogies is another way that researchers and teachers have attempted to help students create connections between new material and previously held schema (DeLorenzo, 1977; Friedel & et al., 1990; Gabel, 1981, 1986; Gabel & Sherwood, 1980, 1984; Gick & Holyoak, 1980).

Applications to the Problem of Transfer

In studies regarding whether or not students are successful at solving problems in science courses, it is often the transfer (or the lack of transfer) of information from one domain to another that forms the basis of their success or failure (Beard & et al., 1980). As an example, multiple researchers have observed how students can solve math problems in one context but struggle with the same or similar problem when the context changes (DeLorenzo, 1977; DeSieno, 1975; Rittle-Johnson & Star, 2009; van Gog, Paas, & van Merriënboer, 2004). Salomon and Perkins (1989) identified two paths for transfer within individuals: "low-road transfer," which they described as reflecting extended practice and resulting in unintentional and implicit (automatic) performance in very similar (near) circumstances, and "high-road transfer," which they described as reflecting deliberate "mindful abstraction" of the elements for transfer and resulting in their explicit application in new (far or distant) circumstances.

Researchers' attempts to create instructional strategies to improve students' ability to transfer knowledge across domains have met with various levels of success over the years (Bransford, Sherwood, Vye, & Reiser, 1986; Carraher & Schliemann, 2002; Lawson, 1985; Pedersen & Liu, 2002b; Pence, et al., 2005; VanderStoep & Seifert, 1993); however, the portion of this research addressing the high-road transfer necessary to solve relatively well-defined problems through the use of constructivist-based practices has met with much greater success (Lawson, 1985; VanderStoep & Seifert, 1993). Short-term interventions have typically failed to improve the degree to which transfer occurs (Salomon & Perkins, 1989), indicating that students most likely require adequate time to develop successful transfer techniques. Another underlying similarity of several strategies that failed to improve transfer has been identified as the use of "blind training," or the teaching of strategies for improving transfer *without* the teaching of why or when to use them (Brown & Campione, 1981). In contrast, methods to improve transfer that engage learners in understanding why and when they should be applied, referred to as “informed training,” have reached much greater levels of successful transfer (Brown & Campione, 1981; Lawson, 1985; Reif, 1983a). Demonstrated improvements in transfer rates have been associated with several specific tasks: (1) students being reminded to use the desired knowledge, (2) students considering the solution to analogs of the problems, and (3) students studying several other examples prior to attempting a problem on their own (Bransford, et al., 1986; Gick & Holyoak, 1980; VanderStoep & Seifert, 1993). Each of these tasks displays an evident connection to constructivist theory.

Role of Transfer in Chemistry

Transfer is central to successful problem-solving and conceptual understanding for chemistry students. This is especially true when students are asked to solve the math-related chemistry problems that compose a large portion of a traditional general chemistry course. According to Benander and Lightner’s examination of the transfer of learning across general education courses (2005), “transfer is not automatic.” Based on their research, instructors should “make transfer expectations explicit” to promote the transfer of learning from one course to another (Benander & Lightner, 2005). Math skills learned in math courses must be shifted into the domain of chemistry before they can be applied to solve a chemistry problem. In order for this information to be transferred, students must recognize what math processes they learned previously and where these processes can be appropriately applied.

“But, which numbers do I plug in where?” Undoubtedly, everyone who has taught or tutored chemistry has been asked this question by college students attempting something as simple as a metric unit or molar mass conversion problem. For the most part, general chemistry students have performed well in their previous math courses and function competently in everyday life. Therefore, many have asked why apparently competent students do not naturally connect the math they have learned previously with the problems they are asked to solve in a general chemistry course. In 1993, Bruer commented on the difficulty that students have transferring math skills to new applications when he wrote, “[s]tudents leave [high] school having the computational skills to solve standard problems but lacking the higher-order mathematical understanding that would allow them to apply their skills in a novel situation." Gabel and Bunce's observation in 1994 supported Bruer's statement; they noted that "improving students' mathematical skills without increasing their conceptual knowledge will have little, if any, effect on their problem-solving capability." Gabel and Bunce then expanded on this idea as it specifically related to transfer when they stated

> if distant transfer is to occur – that is transfer of skills and expertise to a new problem-solving domain that is distinctly different in its stimulus features from the original problem – rudimentary possession of the concepts underlying the problem is a necessity. (1994)

According to constructivism, creating a conceptual understanding of a problem requires active cognition integrating prior knowledge and new information. Therefore, when students are *not* actively engaged in examining what they are learning along with the possible applications of the new knowledge when they are originally obtaining their math skills and when they do *not* reflect on their possession of these skills after they have been acquired, it is unlikely that students will see where and how their skills can be used effectively (transferred) to solve chemistry problems.

Summary

This review of research on how knowledge transfer occurs, it appears that for many general chemistry students, there are two issues blocking this transfer of knowledge. (1) Their math skills are mostly implicit – provided initially as a sets of strict rules that have by college become habit and have rarely if ever been thoughtfully considered. (2) The importance of metacognition – especially as it relates to examining these implicit math skills for their applications to other fields – has not become a key component of their problem-solving process. To address the problem of a lack of transfer between prior math knowledge and chemistry problem solving by general chemistry students at KU, the intervention selected must address both of these issues.

In the previous paragraphs on problem solving and transfer, many successful constructivist-based strategies for teaching have been addressed:

(1) determining students prior knowledge,

(2) scaffolding new tasks,

(3) providing relevant experiences on which to anchor new knowledge,

(4) encouraging active cognitive engagement,

(5) explicitly modeling implicit expert processes for problem solving,

(6) explicitly demonstrating metacognitive skills,

(7) using familiar terms (analogs) or scenarios (analogies) to introduce new topics/skills,

(8) allowing time for cognitive restructuring and mastery activities

(9) providing multiple applications for new topics/skills, and

(10) making expectation of transfer explicit.

In terms of transfer, these methods increase the degree of mindful abstraction performed by the student, which in turn assists them to traverse the high-road of transfer. For mindful abstraction to occur, learners must realize the types of activities they perform implicitly or tacitly before they can reflect on how they approach these tasks and possibly transfer such skills to new domains. This explains the number of methods above focused on transforming implicit/tacit knowledge into explicit knowledge as a first step towards increasing the transfer of knowledge. Alone, in controlled research environments, each of these strategies demonstrates the ability to improve transfer and, thus, the solving of well-defined math-related chemistry problems. However, within research based in a traditional classroom setting examining methods to improve problem solving in chemistry, instructors combine these strategies, along with possibly non-constructivist-based strategies, into larger curricula or pedagogical reforms, and many times this occurs without consideration of their theoretical basis. In the fourth section of this chapter, these classroom-tested methods for improving problem solving in general chemistry courses will be examined to determine which constructivist-based research strategies they employ and whether they would be appropriate for the innovation in the KU general chemistry course.

Considering Social Cognitive Theory in Science Education – an Extension of Constructivism

Aspects of constructivist-based instructional strategies, such as familiar and real-world contexts and focused on teaching metacognitive strategies to promote higher-order reasoning skills, have also been shown to result in students being more motivated to learn new material (Meece, et al., 2003; Phelps, 1996). According to Lorenzo in 2005, previous "studies suggest that success in problem-solving depends on a combination of strong domain knowledge, knowledge of problem-solving strategies, and confidence." Albert Bandura realized the influence that a learner's affect and sense of identity has on his or her learning in the development of his *social cognitive theory*, an outgrowth of cognitive psychology and Vygotsky's social constructivism specifically concerned with learning. In his 1978 article, "The Self System in Reciprocal Determination," Bandura proposed a mechanism by which an individual's (1) behavior, (2) personal attributes (i.e., attitude, cognitive skills, and developmental level), and (3) social environment all influence each other in a reciprocal fashion. In social cognitive theory, ability, including academic self-regulation, is viewed "as a changeable attribute over which one can exercise some control" (Bandura, 1993) by developing and using metacognitive skills – skills regulating the cognitive, motivational, affective, and social aspects of an individual's intellectual function (Bandura, 1993; Zimmerman & Bandura, 1994).

Self-Efficacy

Just prior to initially proposing this holistic view of learning, Bandura introduced the idea of self-efficacy (Bandura, 1977). Then, roughly a decade later, in his book, Social Foundations of Thought and Action: A Social Cognitive Theory, Bandura situated self-efficacy in social cognitive theory and defined it as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances," (1986). A person's perceived self-efficacy has been demonstrated by Bandura and others to influence significantly an individual's academic development by affecting cognitive development and functioning and to be able to differentiate performance even between students with the same level of cognitive skill development (Bandura, 1993; Berry, 1987; Pajares & Miller, 1994; Zusho, et al., 2003). According to Bandura (1993), this occurs because "[s]tudents' beliefs in their efficacy to regulate their own learning and to master academic activities determine their aspirations, level of motivation, and academic accomplishments." Based on the reciprocal nature of motivation and confidence (both personal attributes) on studying and test taking (both behaviors) in classrooms (social environments), social cognitive theory has supported research exploring methods of improving students' academic motivation and confidence.

Impacts on the Classroom

In light of social cognitive theory, it is not enough to provide students with experiences that assist in their successful cognitive development; students must also be confident, motivated, and in possession of an attitude conducive to learning. In addition to self-efficacy, other beliefs such as self-concept (or self-identity), goal-orientation (mastery or performance), perceived usefulness of the content, and level of anxiety towards the subject matter have been shown to be associated with student performance (Bong & Clark, 1999; Meece, et al., 2003; Pajares & Miller, 1994) "largely due to the confidence with which individuals approach a task" (Pajares & Miller, 1994). It has been proposed that self-efficacy is an underlying factor in each of these other beliefs and, therefore, responsible for these observed associations (Bandura, 1986; Pajares & Miller, 1994). While many components of student affect are not controllable by instructors, studies have identified types of instructor-created environments associated with higher levels of motivations and better attitudes: learner-centered classrooms where conceptual understanding and effort are valued, classrooms emphasizing a mastery-oriented approach instead of a performance-oriented approach, and classrooms where students are actively engaged in learning activities (Meece, et al., 2003). Each of these educational environments is strongly informed by constructivist-based pedagogies.

Guided Mastery

Strongly grounded in constructivist-based pedagogies, g*uided mastery*, which Bandura presented as the principle instructional strategy of social cognitive theory, is a combination of cognitive apprenticeship and scaffolding that states explicitly when and how new knowledge and skills should be applied and provides plenty of opportunities for mastery (Bandura, 1986, 1993). Originally, presented by Bandura and his collegues as a social-learning strategy to overcome avoidance behaviors (Bandura, Blanchard, & Ritter, 1969), Bandura later described guided mastery in the following way for educational settings:

> In this approach, cognitive modeling and instructive aids are used to convey relevant knowledge and strategies in graduated steps. Diverse opportunities are provided for guided practice in when and how to use cognitive strategies in the solution of diverse problems. Activities, incentives, and personal challenges are structured in ways that ensure self-involving motivation and continual improvement. Instructive aids are progressively reduced as children's competencies are expanded. Self-directed mastery experiences are then arranged to strengthen and generalize the sense of personal efficacy (1993).

However, based on finding only one education-related article referring to guided mastery following Bandura's introduction of the term for classroom use– a single article in a 1993issue of *Educational Leadership* – it appears that as an instructional strategy this method has never been popularized (Wiske & Levinson, 1993). A broader search of the term outside of educational literature finds that the idea has been adopted by researchers in clinical psychology and medicine as an effective method of desensitizing patients with phobias and other anxieties (V. Carrieri-Kohlman, Douglas, Gormley, & Stulbarg, 1993; Virginia Carrieri-Kohlman et al., 2001; Schneider, O'Leary, & Stewart Agras, 1987; Welch & West, 1995; Williams & Zane, 1989) and in organizational psychology as an on-the-job-training approach (Bandura, 2000; White & Locke, 2003). Instead, in education literature, each of the many pieces of the guided mastery strategy can be found individually and in various combinations but never as the full approach envisioned in Bandura's description above.

Self-Efficacy, Motivation, and Confidence in Science and Math Education

Meece and colleagues confirmed across disciplines that "[a]dolescents reported stronger mastery and performance goals when they perceived their teachers as using learner-centered teaching practices" (Meece, et al., 2003). In 2005, Lorenzo examined whether "an increase in students' conceptual and procedural knowledge" benefits "their attitude and confidence towards problem-solving tasks" and, thereby, reciprocally improves "their problem-solving proficiency" with quantitative problems in general chemistry by using a learner-centered strategy. In this study, Lorenzo demonstrated that an expanded problem-solving heuristic modeling the qualitative aspects of expert problem-solving processes could improve both problem-solving confidence and proficiency in the students (Lorenzo, 2005). Dalgety and Coll noted in their exploration of first-year college students' chemistry self-efficacy that "students' mathematics self-efficacy influences their science self-efficacy," (2006). Combined, the three studies above demonstrate that learner-centered environments, such as those emphasizing the learning of process-skills and when to apply them, increase desirable learner goals and improve both confidence and performance of quantitative problem solving in science, which are also based on a student's beliefs regarding their ability to perform the necessary mathematics. Based on this understanding in addition to those provided earlier for transfer and constructivism, an intervention used to improve student confidence in and performance on quantitative problem solving in the KU general chemistry class needed to include learner centered (constructivist) practices designed (1) to make implicit math abilities/concepts explicit, (2) to improve math self-efficacy (confidence), and (3) to encourage the transfer of both math concepts and self-efficacy to the context of chemistry.

Prior Pedagogies Attempting to Improve Problem Solving in General Chemistry

In a review of constructivist-based pedagogies across a variety of disciplines from 1991 to 2001, Virginia Richardson recognized five characteristics of these instructional strategies regardless of whether they arose from the personal or social vein of constructivism:

(1) "attention to the individual" – including background, development, and beliefs,

(2) “facilitation of group dialog that explores an element of the domain,”

(3) “introduction of formal domain knowledge,”

(4) “provision of opportunities for students to determine, challenge, change or add to existing beliefs and understandings through engagement in tasks that are structured for this purpose,” and

(5) “development of students’ metawareness of their own understandings and learning processes” (2003).

Richardson acknowledges that these characteristics are “not specific practices” but are “approaches to teaching” that support the students as they construct new meaning in classroom settings (2003). The following paragraphs review practices that have been implemented in many general chemistry courses in an attempt to improve students’ quantitative problem-solving abilities, mathematical knowledge/skill transfer, and chemistry self-efficacy and confidence; these include (1) individually implemented strategies, such as factor-label, analog/analogies, and math review texts/websites; (2) remedial and preparatory courses; (3) cognitive apprenticeship models; and (4) tutorials. How constructivism and social cognitive theory have informed these practices and the successfulness of each will be discussed as these prior practices are examined for their usefulness in the KU general chemistry course.

Prior General Chemistry Pedagogies

At the same time as constructivism began drawing chemistry instructors’ attention towards the prior knowledge of individual students in their classrooms, the students in their general chemistry classrooms were becoming much more diverse in regards to gender, race/ethnicity, age, and academic backgrounds due to a national increase in college attendance (Bodner, 1986; Bohning, 1982; J. S. Francisco, Marcella Trautmann, & Gayle Nicoll, 1998; Hanson & Wolfskill, 1998; Kean & Middlecamp, 1983; C. H. Middlecamp & Kean, 1983). Instructors could no longer ignore that all of their students possessed very different prior experiences. In these conditions, researchers discovered that the ability to solve quantitative chemistry problems did not necessarily indicate a conceptual understanding of chemistry and that many students continued to hold a number of preconceptions/misconceptions regarding chemical topics even after significant amounts of instruction (Gabel & Bunce, 1994). When the use of algorithms was shown to be ineffective at promoting a conceptual learning of chemistry, instructors began looking for other solutions. Some looked for more generic methods of addressing quantitative problem solving, such as dimensional analysis and problem-solving heuristics (Bodner, 1987; Bunce & Heikkinen, 1986; Frank & et al., 1987; Goodstein, 1983; Kean, et al., 1988; Lorenzo, 2005; C. Middlecamp & Kean, 1987; Schrader, 1987). These methods were shown to be very effective for obtaining correct answers, but researchers realized that they did not significantly increase students' conceptual understanding because students were simply applying these methods as algorithms (Beichl, 1986; Bunce & Heikkinen, 1986; Evans, Yaron, & Leinhardt, 2008). Some instructors attempted to reach more students by using analogs/analogies of typical chemistry terms/problems as a way to make the work more approachable to students (Gabel & Samuel, 1986; McClure, 1995). However, alone, analogs and analogies did not reliably improve problem-solving performance or conceptual understandings because use of the analog/analogies and its relationship to the original problems confused some students whereas others could not transfer the experiences back to the chemistry context (Friedel & et al., 1990; Gabel & Sherwood, 1983b). In a traditional chemistry lecture, very few instructional methods address both student conceptual understanding and mathematical problem solving effectively when introduced in the classroom as the only intervention.

To address this issue of poor math and problem-solving skills outside of class time, some chemistry instructors wrote mathematical review texts with a goal of assisting students from different mathematical backgrounds to obtain the necessary math skills over the semester (Appling & Richardson, 2003; Ball, 1996; Olive, 1998; Steiner, 1996; Turrell, 2002). Textbook companies published many of these math review texts, packaging some with a related general chemistry text. Other instructors provided students with internet links to websites that they or commercial entities developed as resources to assist students with their problem-solving and math skills (Goldsmith, 1997). As of the fall of 2006, a high school chemistry teacher, Dr. Bob Jacobs, had created the most comprehensive list of such resources (Jacobs, 2002). The portion of his website entitled "Math Skills for Chemistry Tutorials" includes 15 to 50 links to other helpful websites for students to use when learning topics such as dimensional analysis, units, significant figures, scientific notation, and ratios and proportions (Jacobs, 2002). However, as purely supplemental resources, the use and impact of these math review and problem-solving texts and websites cannot be confirmed. A search of the chemical education literature revealed an absence of research regarding the usefulness of such resources for improving math skills or problem solving. The one study that examined the impact of using supplemental web-based review materials on the conceptual understanding of students regarding specific chemistry topics found that the understandings of non-tutorial users were consistently more complete than those of the tutorial users (Donovan & Nakhleh, 2001). Donovan and Nakhleh attributed this to the web-based tutorial being more attractive to the weaker students (2001). As commonly implemented, the above strategies, both those implemented in lecture and those provided as reviews outside of class have, not resulted in improved problem solving or transfer. This should not be surprising, however, considering that none of these strategies considered the individuals' prior knowledge while concurrently requiring active engagement and explicitly displaying the problem solving, transfer, and metacognitive processes of experts.

Remedial and Preparatory Courses

Since the traditional methods used in chemistry lectures to teach problem solving and mathematics did not reliably demonstrate improvements in the abilities of these diverse student populations, some chemistry departments tried to reduce the variability of student backgrounds in general chemistry by restricting admission to these courses based on students' math abilities, prior chemistry experiences, or scores on placement exams (Freeman, 1984; Gellene & Bentley, 2005; Walmsley, 1977b). Many of these departments, then, shifted the students not meeting these prerequisite standards to remedial or preparatory chemistry courses (Angel & LaLonde, 1998; Bohning, 1982; Kogut, 1993; Krannich, et al., 1977; Meckstroth, 1974; Ozsogomonyan & Clinkscales, 1977; Sherman & Sherman, 1976; Wink, et al., 2000). These courses have either been focused on re-teaching the mathematics necessary for general chemistry (Bohning, 1982) or on providing more general problem-solving skills (Kogut, 1993). Such courses have varied from the equivalent of a high school chemistry course taught over the entire semester (Angel & LaLonde, 1998; Freeman, 1984; Gellene & Bentley, 2005; Walmsley, 1977a) to courses as short as one or two weeks prior to the beginning of the fall semester (Bohning, 1982). A few departments even arranged for remediation to be conducted via a concurrently enrolled course during the general chemistry semester (Morse & Clapp, 1980; Pickering, 1977).

Despite these differences, all of these courses include regular meeting times consisting of lectures and working lots of problems. Many also consist of a mastery approach to this material to meet the needs of students who have not reached a formal or abstract cognitive reasoning level. In this approach students are provided with the time that is necessary for them to develop an understanding of the topic/concept before moving on to the next topic (Bronstein, 1986; Freeman, 1984). Based on constructivist theory, such students would benefit from having the opportunity to actively engage (and struggle) with the new material and from being allowed the time that is necessary for the necessary cognitive restructuring to occur (Bronstein, 1986; Bruer, 1993a).

Unfortunately, the curriculum and pedagogies used in most of these remedial and preparatory courses are not explicitly stated; therefore, it is impossible to know how many other constructivist-based practices these courses have employed. As these remedial and preparatory course sections are typically small, it is easy to imagine that they could have consisted of strategies such as active learning, scaffolding, and the modeling of expert processes during class time as methods of attending explicitly to the recognition and development of metacognitive skills that will benefit students in their subsequent enrollment in general chemistry. The mixed results regarding the positive impact of remedial and preparatory chemistry courses on students' future chemistry grades (Bohning, 1982; Bronstein, 1986; Freeman, 1984; Gellene & Bentley, 2005; Jones & Gellene, 2005; Ozsogomonyan & Clinkscales, 1977; Pickering, 1977; Walmsley, 1977a) could be a result of the use or disuse of different constructivist-based strategies composing these various courses. Regardless of the differences in the impact of these courses on student performance, a positive influence on student affect was observed in the studies that examined the attitudes and confidence of students in these courses (Angel & LaLonde, 1998; Bohning, 1982; Wink, et al., 2000).

Cognitive Apprenticeship Models

Even with mathematically or cognitively weaker students removed from the general chemistry classroom, the prior experiences of the remaining students are still diverse, and chemistry instructors still need to address the lack of conceptual understanding students acquire in their courses. Because of this, efforts have been made to alter the overall structure of the general chemistry course by incorporating full pedagogies (not just single strategies) based on a constructivist understanding of how learning occurs. Cognitive apprenticeship developed as one of these methods. Allen Collins and colleagues (1987) described cognitive apprenticeship teaching methods as “designed, among other things, to bring these tacit [expert] processes into the open, where students can observe, enact, and practice them with help from the teacher and from other students.” They outlined four types of expert knowledge as necessary components of cognitive apprenticeship: domain knowledge (vocabulary, syntax, and rules), problem-solving strategies and heuristics (process), control strategies (when and where to apply different strategies), and learning strategies (methods of learning the domain knowledge, the problem-solving, and the control strategies) (Collins, Brown, & Newman, 1987). Cognitive and metacognitive skills are acquired in cognitive apprenticeship via observations of expert processes and skills combined with plenty of guided and supported practice and reflection, and this usually occurs through several constructivist-based strategies including modeling, coaching, and scaffolding (Collins, et al., 1987; Dennen, 2004).

Research on full models of cognitive apprenticeship in general chemistry courses have most often appeared as research on the instructional intervention called Peer Led Team Learning (PLTL) (Gosser & Roth, 1998; Tien, Roth, & Kampmeier, 2004) and as research on other workshop-based innovations incorporating guided inquiry as a required course component (Báez-Galib, Colón-Cruz, Resto, & Rubin, 2005; Hanson & Wolfskill, 2000; Lewis & Lewis, 2005; Wolfskill & Hanson, 2001). All of these cognitive apprenticeship-based strategies consist of the following components: required workshops/tutorials sessions integrated with other course components, highly involved faculty, trained peer-leaders, set learning teams, and coherent yet challenging collaborative group assignments (Gosser

& Roth, 1998). In these cognitive apprenticeship models, the peer-leaders – typically more advanced students who recently completed the course successfully – serve as facilitators of the required problem-solving workshops. The peer-leaders are trained to engage the students and scaffold their learning experiences while the students collaboratively attempt to solve the problems by using specific problem-solving strategies (Gosser & Roth, 1998). The peer-leaders also help students focus and reflect on their process while problem solving (Hanson & Wolfskill, 2000). The professors of the related lectures are responsible for illustrating during lectures the expert problem-solving and metacognitive processes for the students to model in their own practice and are also responsible for monitoring and providing feedback to individuals and teams of students when necessary (Hanson & Wolfskill, 2000). According to Gosser and Roth's evaluation of multiple PLTL sites (1998), there has been a "statistically significant improvement in the grades, retention, and levels of student satisfaction" at each of them. Uses of cognitive apprenticeship techniques in general chemistry courses have shown that they help refocus the students on developing a conceptual understanding of the material and improve students confidence and attitude towards the course (Duchovic, 1998).

Variations of the cognitive apprenticeship model have been very successful at improving the general chemistry experience for many students; however, such techniques require a highly organized structure, time to recruit and train peer-leaders, changes to the traditional course lectures and grading structure, and significant university support (Báez-Galib, et al., 2005). As a result, other researchers have realized the need for methods capable of bringing multiple constructivist-based practices into courses without requiring an over-haul of a whole course. Several chemical educators have tried to create cognitive apprenticeship-like experiences for student via internet-based resources and tutorials without the presence of the physical workshops (Crippen & Earl, 2004; Lagowski, 1998; van Gog, et al., 2004; Wolfskill & Hanson, 2001). One of the most promising of these methods is the use of process-oriented worked examples delivered via the internet (Crippen & Earl, 2004; Taconis, et al., 2001; van Gog, et al., 2004). The term process-oriented is used in this strategy to specify that the worked-examples "seek to attain transfer by having novices mimic experts' problem-solving behaviour," instead of simply providing the steps the expert took to achieve the correct answer (van

Gog, et al., 2004). These process approaches focus on the metacognitive questioning, information gathering, problem restructuring, and planning that experts engage in when solving problems. Studies of worked-examples without this additional metacognitive focus have previously shown that the method is more effective at promoting concept/skill transfer than simply having students work an equivalent number of problems on their own (Taconis, et al., 2001). In a meta-analysis of research on science problem-solving approaches across science domains via experimental designs, Taconis and his colleagues focused on the relative impacts of these approaches on student learning outcomes; they found that the largest effects were obtained with approaches designed to improve the quality of the students' knowledge base by modeling the processes of expert problem solving (2001). Van Gog and his colleagues believed that the addition of a process-orientation to worked examples would assist students in building mental models, stimulate conceptual understanding, and aid in far transfer (van Gog, et al., 2004). As students view more worked-examples, they can become responsible for filling in blanks in the examples. In this way the strategy can be faded away (somewhat like scaffolding) so that the student accepts more responsibility for working the example on his own over time (van Gog, et al., 2004).

Crippen and Earl combined the study of worked-examples with student training in self-explanation (metacognitive) strategies for quantitative problem solving using a web-based weekly quizzing system (2004). Students were allowed a full week to work on a quiz and during that time students could change their answers at any time and received immediate feedback regarding the correctness of their responses. The worked examples and metacognitive suggestions prompts were provided for each multi-step problem (Crippen & Earl, 2004). This design engaged students in studying the worked-examples and metacognitive strategies by tying them directly to weekly graded quiz questions. The provision of immediate feedback encourages students to continue trying and reinforces their strategies when they have answered correctly, and the unlimited attempts over a whole week allow most students the time necessary for any transfer to occur as a result of their experiences with the worked examples (Taconis, et al., 2001). By this method, several constructivist-based strategies can be brought together in an environment asynchronous to any course meeting times. Under these conditions, many students accessed the worked examples and metacognitive resources while working the quiz problems (Crippen & Earl, 2004). Assessments of these web-based worked examples, showed that they were very positively received by the students and that use of the examples and metacognitive strategies was associated with improved performance and self-efficacy (Crippen & Earl, 2004). While this was viewed as a possible option for the intervention necessary in the KU general chemistry course, its purpose did not exactly match the needs of both types of student identified in the preliminary study, those with insufficient math skills and those struggling with transferring knowledge between math and chemistry domains. The web-based process-oriented worked examples provided neither a review of the necessary math skills nor explicitly stated connections between the processes used by expert chemists to solve problems and the math problems with which students are more familiar.

Online Homework and Web-Based Tutorials

Other internet-based instructional tools, such as electronic homework systems and online tutorials, have become very popular in general chemistry courses over the past decade. Most visibly, the introduction of electronic homework provided a solution to the problems of grading and delayed-feedback of homework assigned to large general chemistry lecture sections, but this method of homework delivery has also been shown to provide additional benefits to the students and the instructors (Spain, 1996). In large lectures with paper-based homework, it had become common for only a few problems from homework assignments to be graded for correctness or for the whole assignments to simply be graded for attempts if the homework assignments were graded at all (Cole & Todd, 2003). In such an environment, very little incentive existed for students to engage actively in working homework problems (Freasier, Collins, & Newitt, 2003; Spain, 1996). By making the grading of homework for correctness a less onerous task, faculty were much more likely to include it as a graded component again (Cole & Todd, 2003). As mentioned with the web-based worked examples discussed previously, the provision of immediate feedback when students are working problems helps to keep students engaged in the process, and this feedback informs students when their answers are incorrect, providing students the impetus to reconsider their initial attempts at a problem and try it again

(Spain, 1996; Vician & Charlesworth, 2003). The ability to submit problems multiple times (possibly, an unlimited number of times) allows an engaged student to actively pursue mastery of the problem (Freasier, et al., 2003; Taconis, et al., 2001; Vician & Charlesworth, 2003). Research on how scaffolding and feedback should be designed to support student learning in these online homework or tutorial environments provides the same suggestions as seen with the use of these techniques in personal (face-to-face) tutoring. (1) Providing feedback regarding how a student is incorrect based on a knowledge of common misconceptions is more beneficial than simply informing a student that he or she is incorrect (M. Oliver-Hoyo, 2001). (2) Scaffolding effectively requires process information that is "just-in-time, just-enough and gradually fading," (Dabbagh, 2003). Research on the use of electronic homework systems, even in the absence of other major course interventions, has demonstrated its benefit on student course performance and motivation (Freasier, et al., 2003; Spain, 1996). Some electronic homework systems have accompanying tutorial webpages provided to students for use as a quick reference when working the problems. Students have indicated that they find these tutorials beneficial to their learning (Arasasingham, et al., 2005; Freasier, et al., 2003; Vician & Charlesworth, 2003).

Where the above systems focused on the homework and may have contained tutorial features, other systems have the opposite orientation; these mainly tutorial systems have also become popular in chemistry courses. Many of these online tutorials are provided to students as supplemental instruction on a specific topic (such as limiting reagents, calculator skills, or stoichiometry) or on the applications and connections of course material to other subjects or societal problems (Donovan & Nakhleh, 2001; Herman, et al., 2005; Parrill, 1996; C. Wood & Breyfogle, 2006). Research on curriculum built around the use of these kinds of tutorials has indicated mixed results at improving student achievement. This is likely due to the lack of quantitative or qualitative problem-solving typically associated with these tutorials and, thus, their inclusion of very little modeling of the expert processes necessary to perform well when solving problems on the course exams. However, integration of these tutorials into courses consistently results in greater student engagement (Donovan & Nakhleh, 2001; Herman, et al., 2005; C. Wood & Breyfogle, 2006). Therefore, it would appear that while students are interested in the material, the fact that they do not necessarily have to use this new knowledge immediately results in less transferring of expert process, skills, and concepts.

Versions of one web-based tutorial focusing on the improvement of students' calculator-skills and mathematical skills was implemented at two separate institutions (Pienta, 2003; Pienta, et al., 2001). The web-based math and calculator skills tutorial created by Pienta at the University of Iowa (2003) was modeled on a web-based calculator-skills tutorial that he and others developed earlier with the assistance of the Shodor Education Foundation at the University of North Carolina – Chapel Hill (Pienta, et al., 2001). At UNC–Chapel Hill, the goal for the web-based tutorial was to provide "a simple method to assure that students practiced simple algorithmic mathematical skills, including the use of their calculators, before the start of the course quizzes and tests" in such a way that students in need of remediation or additional practice could be identified early (Pienta, et al., 2001). A self-test/placement-test was associated with each iteration of this tutorial, allowing students and instructors to check student understanding and determine which level of chemistry the student should take. Student interaction with these tutorials was positively associated with student course performance (Pienta, 2003). As a voluntary assignment, use of the tutorial in these studies was associated with increased motivation (Pienta, et al., 2001). Its voluntary nature probably reduced the overall effectiveness of the tutorial in the course; as Pienta (2001) mentions, "[e]vidence suggests that about half of the group that did not participate in the tutorial should be encouraged to seek more intervention." The math-related chemistry topics that needed to be included in the intervention for the KU general chemistry students were the same as those covered in the Pienta's web-based tutorials, such as scientific notation, proportions, units, conversions, and stoichiometry (Pienta, 2003; Pienta, et al., 2001); but, the design and implementation of the intervention to be used at KU needed to promote the engagement of all students in the course. Simply focusing on the math and calculator skills of students was not deemed sufficient for the design of a similar tutorial at KU. Those skills only represent one portion of students' difficulties with this math-related material – the lack of the skills due either to having never learned the skills or having forgotten them due to lack of recent use (Pienta, 2003). Just as important to success in chemistry is student knowledge and confidence regarding how to transfer mathematical skills learned in previous math courses and everyday lives into the chemistry context.

Choosing the Intervention

Based on this review of the literature on constructivist-based practices that have been previously integrated into general chemistry, it was determined that none of the previously researched approaches sufficiently matched the goals of the intervention needed for the KU general chemistry course. Therefore, a new intervention needed to be created, one that would incorporate many of the strategies seen in the prior successful interventions but would do so in a manner that fit the current structure of the KU course.

Chapter 3

Preliminary Research: Overview, Results, Discussion, and Implications

Purpose and Overview of Exploratory Preliminary Research

An exploratory evaluation was conducted to examine the demographic and academic background characteristics of students enrolled in the first semester general chemistry course at the University of Kansas in the fall of 2005. This preliminary study was undertaken to gain a better understanding of the backgrounds of students in the course and to determine which background variables were associated with student performance. Observations of students in the general chemistry course had led to the idea that a significant portion of the students in the course were continuing to struggle with introductory math-related chemistry concepts at the end of the course; however, this idea was unsupported by any quantitative evidence. Therefore, this preliminary study was also performed to determine what portion of the students perceived that they were continuing to struggle throughout the semester with the math-related chemistry topics, which were introduced at the beginning of the course, and to determine whether student backgrounds were related to this perceived level of struggling. To explore these questions, the preliminary study consisted of the administering and analysis of an end of the semester survey (provided via BlackBoard ™) and analyzing data obtained from university records regarding the academic and demographic backgrounds of students and their performance in general chemistry.

While the surveys that students completed in the course were associated with their *real* student numbers, the data from university records was coded to nonspecific student identifiers. Therefore, it was not possible to relate a specific student's survey responses to a student's university data, including course performance. For this analysis, all identifying information was removed from both sets of data, and all descriptions of and results from this preliminary study evaluation are reported in the aggregate and are used purely to provide a better description of the students taking general chemistry. Findings from this preliminary study strongly informed the creation, implementation, and analysis of a web-based math and problem-solving tutorial called ReMATCH.

Overview of the First Semester General Chemistry Course in the Fall of 2005

Course Structure of General Chemistry

The first-semester general chemistry course in the fall of 2005 proved to be a very stable course for this study. The professor was teaching the course for the third consecutive, fall semester using the same textbook and electronic-homework system along with the same lecture- and lab-structure. This structure included a 50-minutes lecture class that met three days per week and a weekly three-hour lab. Students met for lecture as a single group in an auditorium that seated 990 students and were divided into groups of 20 or fewer students for their lab sections, resulting in over 40 lab sections. In the fall of 2005, over 900 students enrolled in the course, and, of these, 877 students completed the course for a grade.

Student grades included a maximum of 700 points from lecture and 300 points from lab. The lecture component consisted of grades from three lecture-exams (100 points each), one final exam (200 points), and electronic homework via WebAssign® (200 points) (Advanced Instructional Systems, 1997). The lab component consisted of grades from pre-labs, weekly quizzes, weekly lab notebooks, and weekly lab reports. As the textbook for this course, the students used an instructor-modified copy of *Chemistry*, 8th edition by Chang that came packaged with course study materials (Chang, 2003). Students had several resources available to them for assistance with this course: instructor office hours, TA office hours, and a general course email account monitored by TAs. The only prerequisite for general chemistry was for students to be *calculus-ready*; however, there was no method in place for enforcing this prerequisite at the time of this research.

Selecting the Enrolled Students Group for Analyses in 2005

From the over 850 students initially enrolled in general chemistry, 828 students completed the course for a grade of A, B, C, D, or F, five students received credit (C or above) or no credit (D or F), and 44 students withdrew from the course after the cancellation period. Students retaking general chemistry at KU typically do not retake the lab component. Therefore, to remove the effect of prior general chemistry experiences from this evaluation, the sample for this study included only students who enrolled in a lab section and earned a grade of A to F in the course. This restriction resulted in the removal of 38 students who did not enroll in a lab section. The remaining students will be referred to as the *enrolled students* group ($N = 790$) for the fall of 2005. Unless indicated, all of the data shown in the preliminary research describes this group of e*nrolled students*.

Overview of Data from University Records

Demographic Data

According to the demographic information from university records shown in Table 1, the course consisted of slightly more males than females and had little ethnic diversity: Nearly 82% of the students identified themselves as white when applying to the university. Most of the students enrolled in this course relatively early in their academic path: Over 80% of the enrolled students were at the freshmen or sophomore level ($Level_{enrolled}$).

It was also possible to track a student's status when entering the university (i.e. directly from high school or transferring from another institution). This was labeled $Status_{entry}$ and consisted of three levels:

(a) *Freshman* (any student enrolling at the institution directly out of high school regardless of any college credit earned through advanced coursework prior to high school graduation),

(b) *Transfer* (any student transferring 24 or more credit-hours of higher education coursework completed after high school graduation), and

(c) *Other* (any student for whom English is not his/her native language who must enroll in English-proficiency coursework when entering the institution, any student entering the institution in the spring semester, and any student entering the institution with fewer than 24 credit-hours of higher education coursework completed after high school graduation).

Table 1 shows that over 85% of the students in general chemistry had Freshman listed as their $Status_{entry}$. Finally, the difference, reported in years, between the fall of 2005 and each student's matriculation term was labeled $\Delta Years_{entry}$. The majority of students, over 60%, were in their first year at the university, nearly 25% had been at the university for one full year previously, and approximately 15% had been at the university for two or more years prior to the fall of 2005.

Most of the university departments that list this general chemistry course in the requirements for their majors suggest that students planning to graduate in four years enroll in the course in the first semester of their first year. A few degree plans suggest students enroll in the course during the fall semester of their second year. The $Status_{enrolled}$ variable was created to dissociate students in their first fall semester at the university from students with previous credit earned from the university in prior years. $Status_{enrolled}$ consisted of six levels: (a) first-semester freshman, (b) first-semester transfer, (c) prior freshman, (d) prior sophomore, (e) prior junior, and (f) prior senior. Table 2 shows how $Staus_{entry}$, $Level_{enrolled}$, and $\Delta Years_{entry}$ were combined to create the $Status_{enrolled}$ variable. As shown in Table 2, over 50% of the general chemistry students were in the fall semester of their freshmen year, approximately 9% were in their first fall semester as transfer students, and approximately 41% where students who had completed at least one prior fall semester of coursework at KU.

Academic Background Data from University Records

High school GPA.

Of the *enrolled students*, over 90% reported their high school grade point averages ($HSGPA_{reported}$) to the university. Different school districts reported high school grade point averages on different scales that were either unweighted scales (grades in all courses are worth equal points) or weighted scales (grades in advanced courses are awarded more points than those in standard-level courses). Enrolled students in 2005 had $HSGPA_{reported}$ from 10 different scales: 4-point unweighted, 4-point weighted, 5-point unweighted, 5-point weighted, 7-point weighted, 8-point unweighted, 12-point unweighted, 12-point weighted, 100-point unweighted, and 100-point weighted. On some weighted scales, it is possible for students taking advanced coursework to obtain values above the value used to label the scale (i.e. a student earning A's in Advanced Placement and other courses graded on a 4-point weighted scale could graduate high school with a grade point average above a 4.0).

For admission purposes, the university converts all of these $HSGPA_{reported}$ values to a 4-point scale ($HSGPA_{converted}$); in this process, any $HSGPA_{reported}$ values from weighted scales that convert to a value above 4.0 are simply reported as a $HSGPA_{converted}$ value of 4.0. Therefore, values for $HSGPA_{converted}$ ranged from 2.00 to 4.00. In 2005, students in general chemistry had a $HSGPA_{converted}$ average of 3.62 (SD = 0.40). The histogram in Figure 3 shows the distribution of HSGPAs compared to a normal curve. The obvious divergence from a normal curve is due to the distribution being negatively skewed and exhibiting a strong ceiling effect resulting from the values above 4.0 being truncated for $HSGPA_{converted}$. Based on this, $HSGPA_{converted}$ is not an acceptable version of this variable because the analyses planned for this data include correlations and ANOVAs, which assume that variables have population distributions that approximate a normal curve. Therefore, an attempt was made to find a version of this variable that was more normally distributed and thus more appropriate for use in further analyses.

To find a more normally distributed version of this HSGPA variable while having no access to the conversion program used by the university admissions office to convert from $HSGPA_{reported}$ to $HSGPA_{converted}$, a scatterplot of $HSGPA_{reported}$ and $HSGPA_{converted}$ was created that included only students with $HSGPA_{reported}$ values from 4-point unweighted and 4-point weighted scales (see Figure 4). The plot clearly illustrated that the GPA conversion program used by the admissions office did not technically convert between unweighted and weighted scales but instead simply truncated weighted values above 4.0 to a value of 4.0. This knowledge was combined with the fact that 84.5% of the students had $HSGPA_{reported}$ values from one of the two 4-point scales: 46.5% reported on a 4-point unweighted scale and 38.0% reported on a 4-point weighted scale. This left only 5.8% of the students with $HSGPA_{reported}$

values on all the other scales combined since 9.7% of the students were transfer students who did not have a $HSGPA_{reported}$ value. For those students with values from the less frequently used scales, a cross-tabulation of the scale-type versus the $HSGPA_{reported}$ values showed that none of the $HSGPA_{reported}$ values for this group were above their scale's maximum. For example, all students on a 5-point weighted scale had $HSGPA_{reported}$ values below 5.0 and all those on a 100-point weighted scale had $HSGPA_{reported}$ values below 100 points. Thus, when a $HSGPA_{reported}$ value from one of these less frequently used scales was transformed into $HSGPA_{converted}$ by the admissions office, there was concern about possible truncations of the $HSGPA_{converted}$ values because their values were all below 4.0.

These findings led to the creation of a new high school grade point average variable, simply referred to from here on as *HSGPA*. HSGPA included the original $HSGPA_{reported}$ values from 4-point unweighted and 4-point weighted scales, while including the university-created $HSGPA_{converted}$ values from less frequently used scales. The distribution HSGPA resembled a normal distribution (Figure 5). Lacking the ability to look at students' high school transcripts and recalculate grade point averages based on individual classes and grades, this new HSGPA variable was the most accurate and useful version possible. HSGPA exhibited a mean of 3.65 with a standard deviation of 0.452. While only slightly different from the mean and standard deviations reported earlier for $HSGPA_{convereted}$, this version was appropriate for use in later statistical analyses that assume normally distributed variables.

Table 1
Demographic Data for General Chemistry in Fall 2005

Variable	Categories	% of Enrolled Students (N = 790)
Gender	Female	48.1
	Male	51.9
Ethnicity	African American	3.3
	American Indian	1.4
	Asian	5.2
	Hispanic	3.5
	Non-Resident Alien	2.3
	White	81.9
	Unknown	2.4
$\text{Level}_{\text{enrolled}}$	Freshman	57.8
	Sophomore	24.7
	Junior	13.0
	Senior	4.4
$\text{Status}_{\text{entry}}$	Freshman	85.4
	Transfer	11.6
	Other	2.9
$\Delta\text{Years}_{\text{entry}}$	0	60.6
	1	24.6
	2	8.6
	3 or more	6.2

Table 2

Status When Enrolled (Status$_{enrolled}$) in General Chemistry in Fall 2005

ΔYears$_{entry}$	Status$_{entry}$	Level$_{enrolled}$		Status$_{enrolled}$	% of Enrolled Students (N = 790)
0	Freshman	Freshmen Sophomore Junior	→	First Semester Freshmen	50.3
0	Transfer	Freshmen Sophomore Junior Senior	→	First Semester Transfers	8.9
1 or greater	Freshman, Transfer, or Other	Freshman	→	Prior Freshman	7.6
		Sophomore	→	Prior Sophomore	19.4
		Junior	→	Prior Junior	10.1
		Senior	→	Prior Senior	3.7

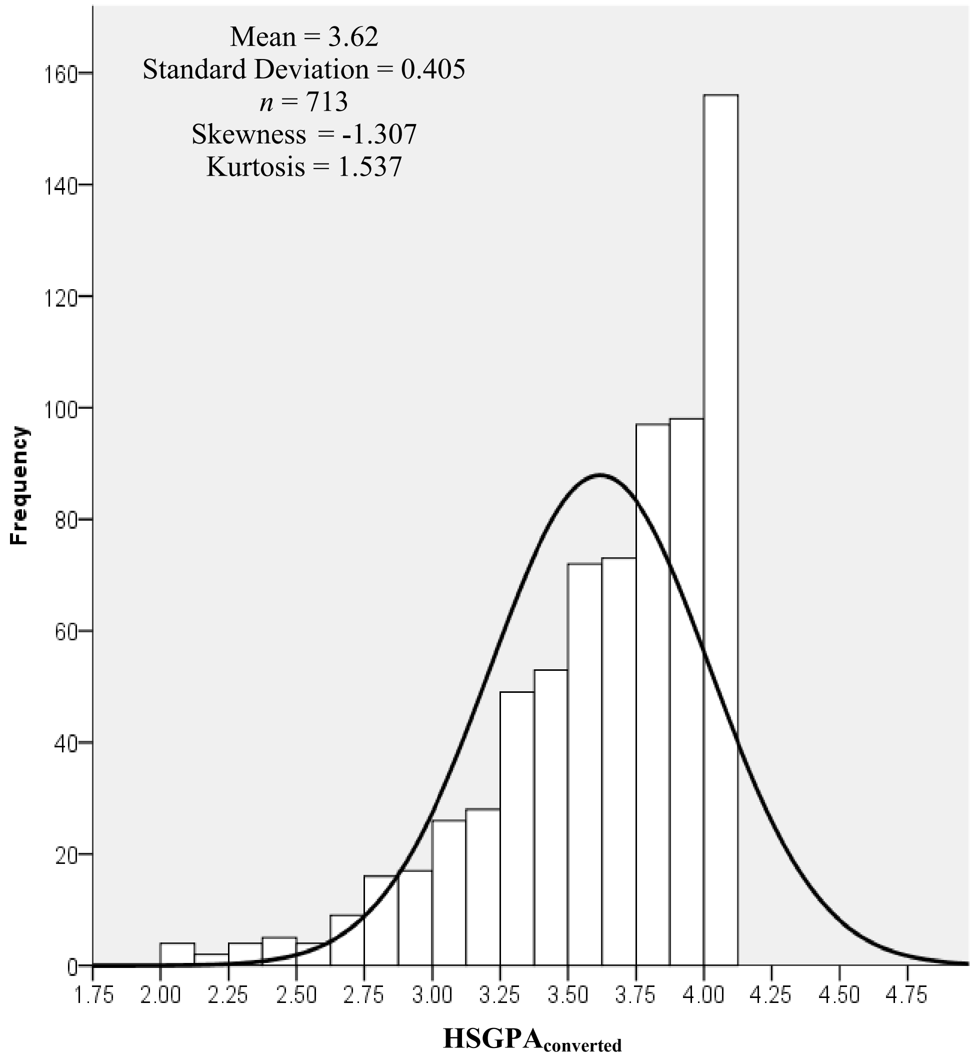


Figure 3. The histogram shows the distribution of high school GPAs (HSGPA) for students in general chemistry for the fall of 2005. This distribution does not fit a normal curve very well due to a strong ceiling effect.

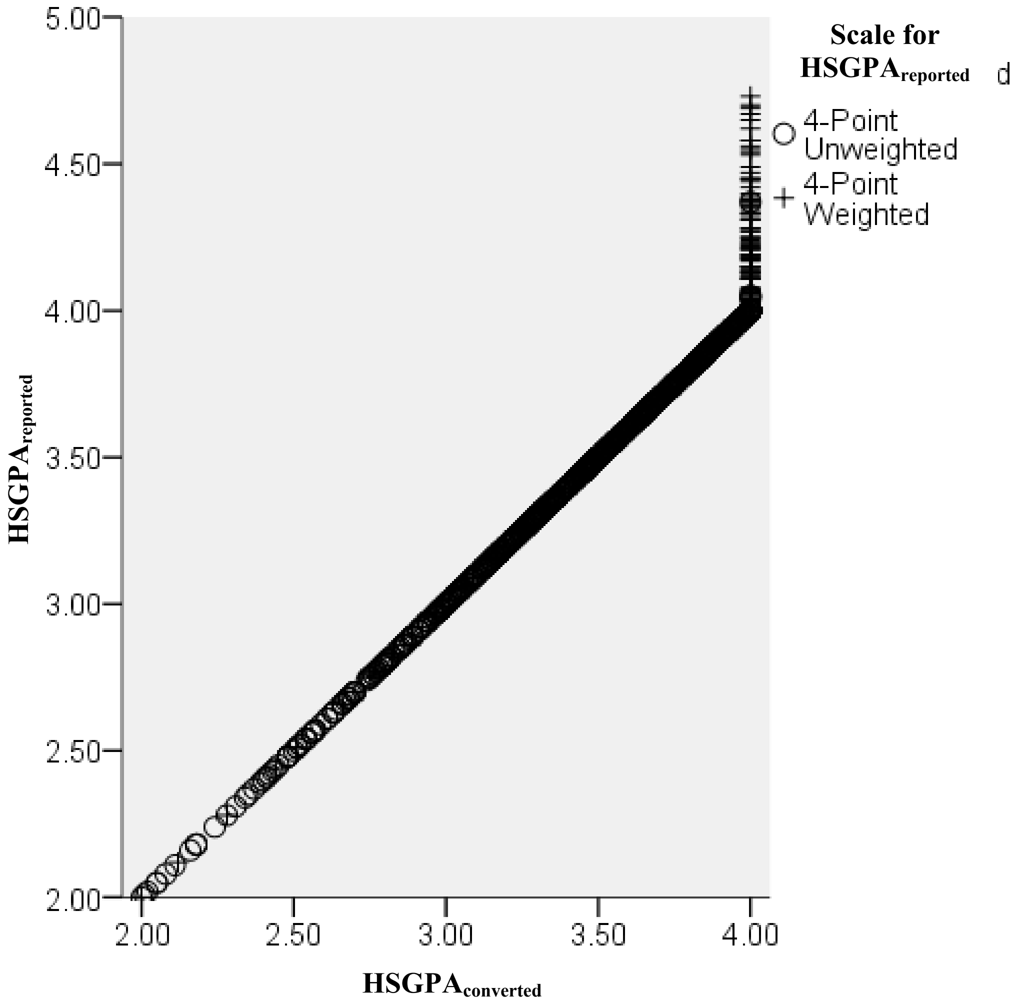


Figure 4 Displays the scatterplot of $HSGPA_{converted}$ plotted against $HSGPA_{reported}$. The perfectly linear relationship between these variables until $HSGPA_{reported}$ goes beyond 4.0 and, then, resulting truncation of $HSGPA_{reported}$ beyond that point (illustrated by the vertical line of points) demonstrates that the software used by KU's admissions office to *convert* HSGPAs above 4.0 to a 4-point scale simply truncates any HSGPA on a 4-point weighted scale that are above 4.0 to simply a 4.

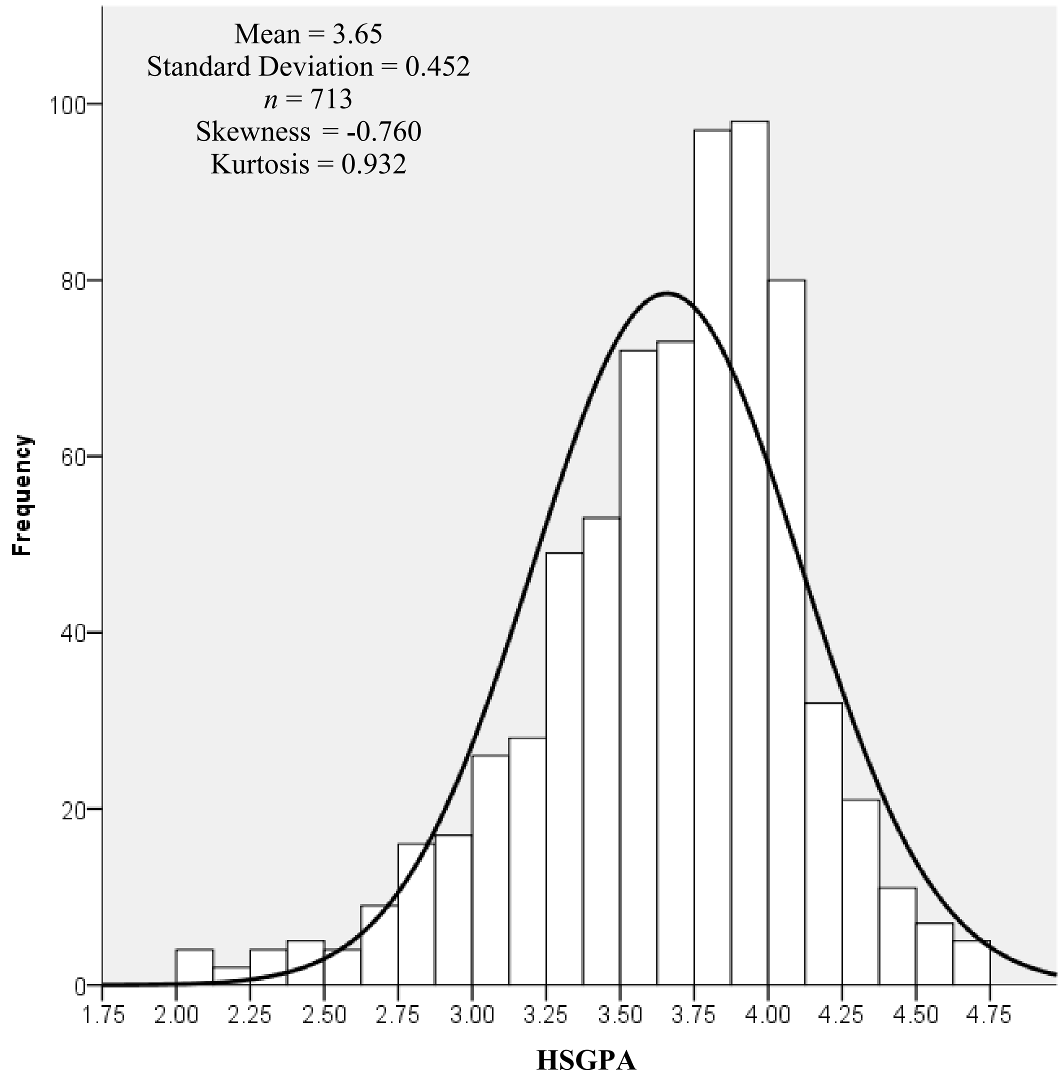


Figure 5 Presents histogram of illustrating the relatively normal distribution of HSGPA.

Prior university GPA.

Over 42% of the enrolled students attended the university for at least one year prior to enrolling in general chemistry in the fall of 2005. Therefore, this subset of students had university grade point averages (UGPA); these students' UGPAs ranged from 0.00 to 4.00, with an average of 2.94 (*SD* = 0.700). The histogram in Figure 6 shows the distribution of UGPAs. The distribution visually appears to fit a normal curve relatively well.

ACT scores.

Since ACT scores, specifically the math sub-score, have been shown in numerous studies to be good predictors of general chemistry performance, I examined the ACT data collected by the chemistry department to determine whether this was true for students in this general chemistry course. Out of all of those enrolled, 87% of the general chemistry students reported ACT scores to the university. These students had an average ACT composite score ($ACT_{composite}$) of 25.4 (*SD* = 3.74) and an average ACT math sub-score (ACT_{math}) of 26.3 (*SD* = 4.16). As shown in Figure 7, both of these variables were normally distributed within the enrolled students.

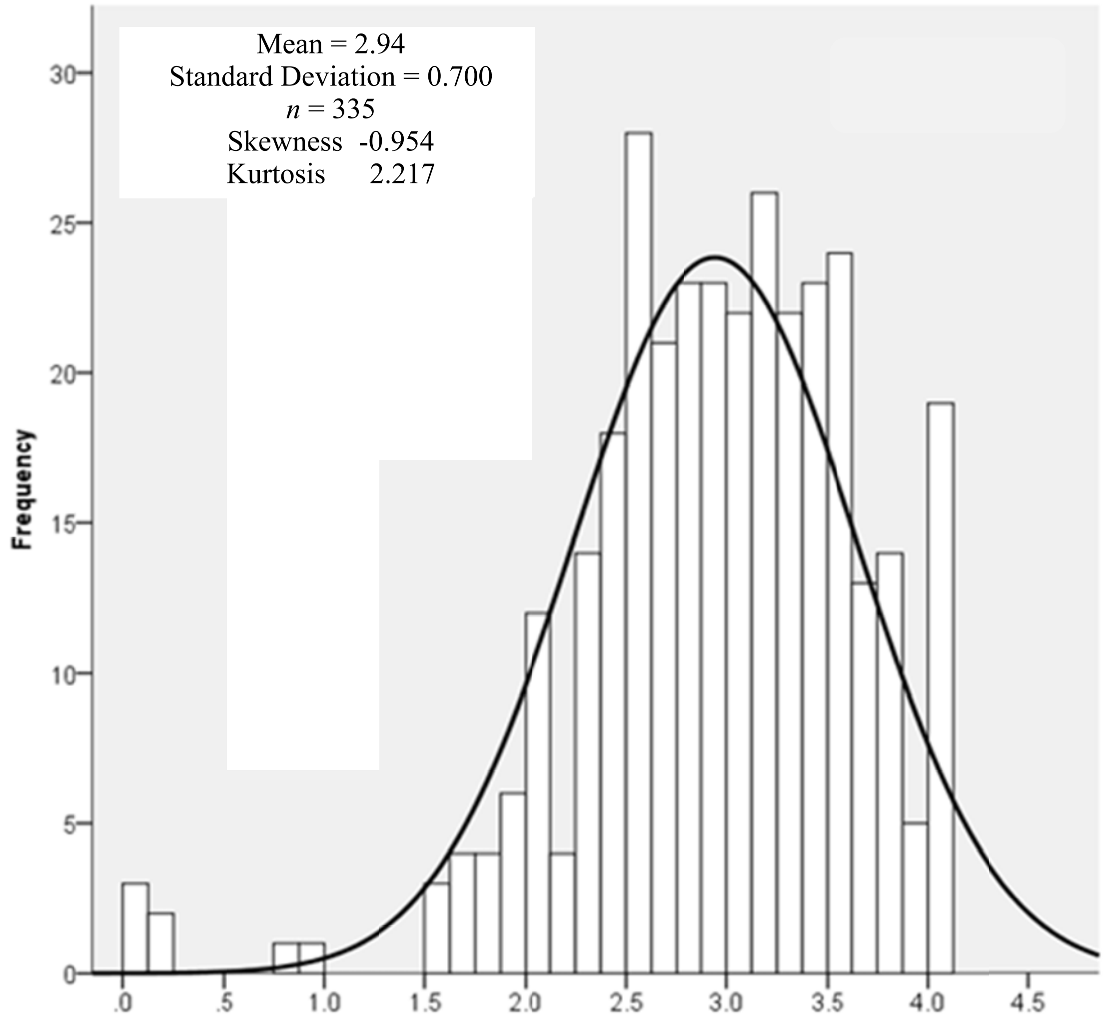
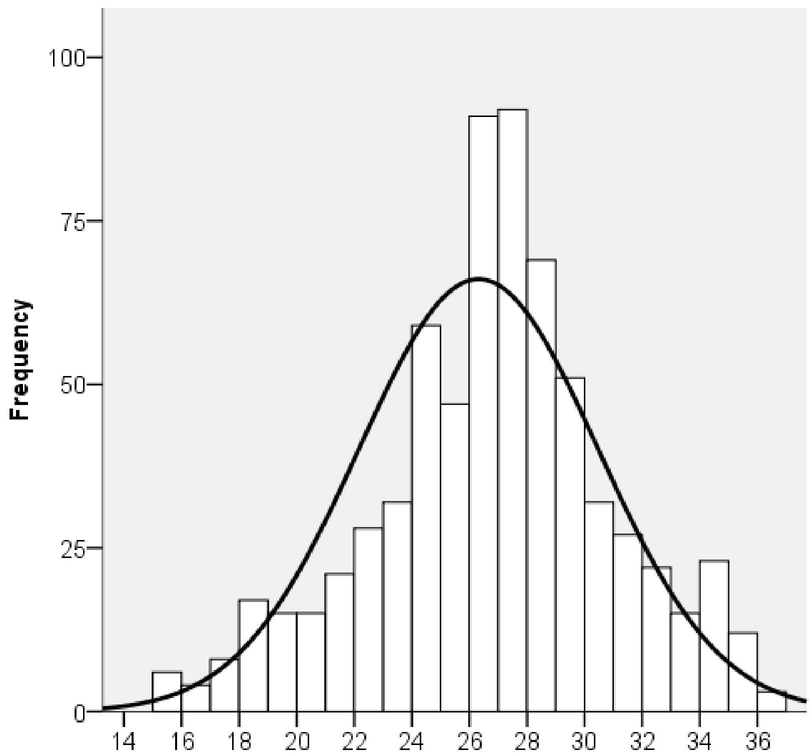
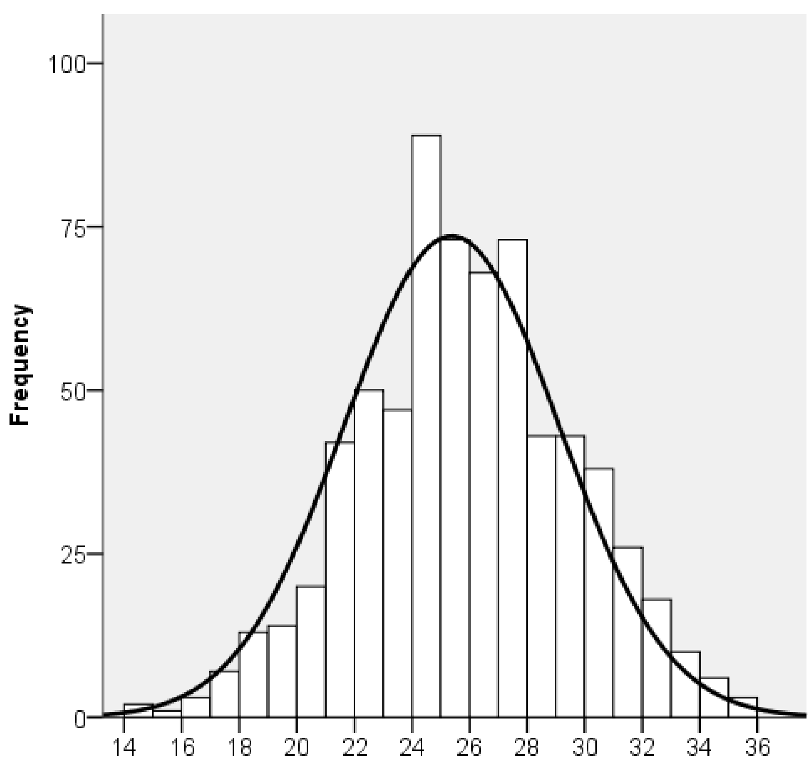


Figure 6. The histogram shows the distribution of previous university GPAs (UGPA) for students in general chemistry for the fall of 2005. This distribution roughly fits a normal curve.



ACT_{math}

Mean = 26.3
Standard Deviation = 4.16
n = 689
Skewness = -0.226
Kurtosis = 0.096



$ACT_{composite}$

Mean = 25.4
Standard Deviation = 3.74
n = 689
Skewness = -0.034
Kurtosis = -0.112

Figure 7 [Top] Displays a histogram of ACT_{math} with a relatively normal distributions.
[Bottom] Displays a histogram of $ACT_{composite}$ with a distribution very close to normal.

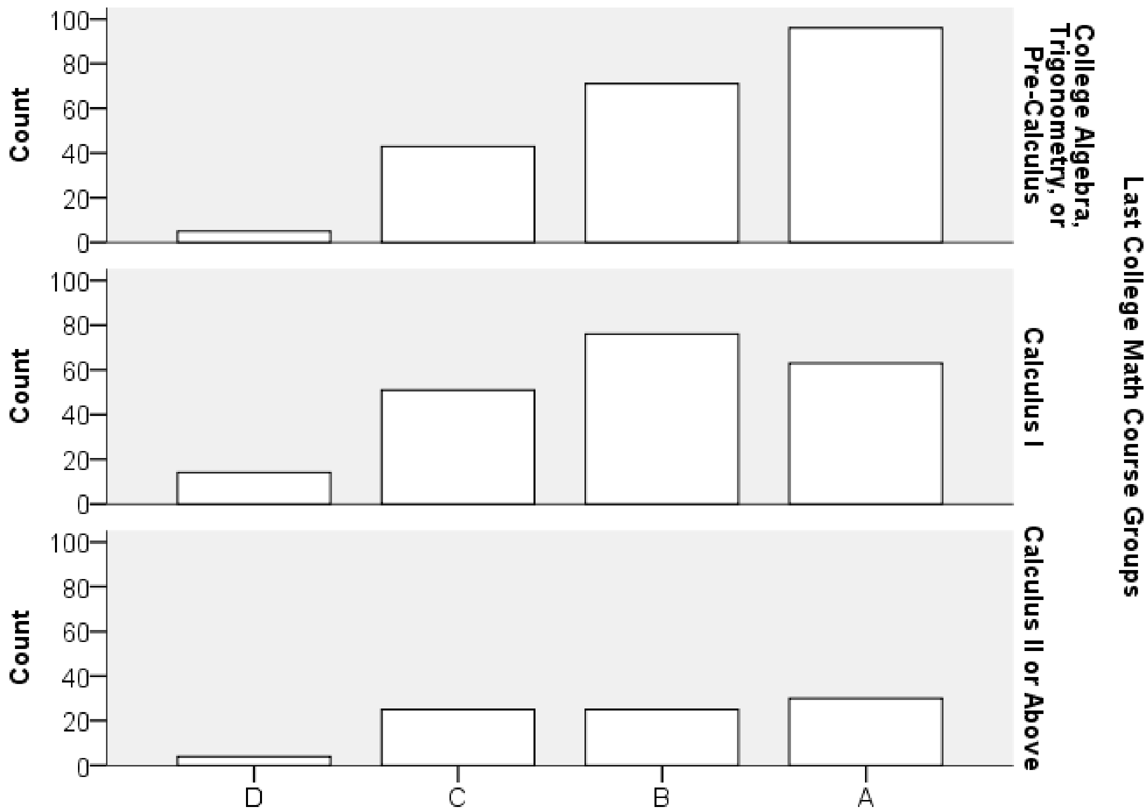
Last math grade.

Grade earned by students in their last college-level math course, $Math_{grade}$, was the final background variable examined from university records data. A student's grade in his or her last math course was shown in the previous chemical education research literature to be a good predictor of performance in general chemistry, better even than ACT_{math} in some studies (Mintzes, et al., 2006; Tai, et al., 2005). This data from university records included the university code for the last college-level math course ($Math_{last}$) for which students earned credit by receiving a letter grade of A through D ($Math_{grade}$). From this data, $Math_{college}$ was created and included four categories: (1) No College Math, (2) College Algebra/Trigonometry/Pre-Calculus, (3) Calculus I, and (4) Calculus II and Above. Out of all enrolled students, 64.2% of the class had a grade for a previous college-level math course. Interestingly, 42.2% of first-semester freshmen had a letter grade for a previous college-level math course. The average $Math_{grade}$ for students in general chemistry was 3.04 (*SD* = 0.892). Figure 8 shows that $Math_{grade}$ lacked a normal distribution for each level of $Math_{college}$; therefore, this variable's usefulness in further analyses was limited. Table 3displays the frequency of the last math courses taken by the general chemistry students. Typically, students completed their last college-level math course two to three semesters prior to enrolling in general chemistry; for 44% of the students, their most recent college-level math experience occurred during the last one or two semesters.

Table 3

Last College Math Course for Students in General Chemistry

Is prior college-level math credit present?	$Math_{college}$ Category	Enrolled Students (%) *(N = 790)*
Yes	--	65.1
	Below College Algebra	0.9
	College Algebra/Trigonometry/Pre-Calculus	27.6
	Calculus I	25.8
	Calculus II and Above	10.8
No	--	34.9



$Math_{grade}$

Figure 8 Displays bar graphs detailing the distribution of A to D letter grades in three categories each of the three categories for $Math_{last}$

Course Performance in the Fall of 2005

The average grade for students completing general chemistry with a grade of A through F was a little above a B- (n = 790, M = 2.80, SD = 1.02). When these grades were displayed as a histogram, the curve modeled a normal curve fairly well based on applying the rule of thumb that both the skewness and kurtosis values should fall between ±1.0 (See Figure 10). The frequency of all grades earned in general chemistry (GC_{grade}) including the grading options of *credit* (CR), *no credit* (NC) , and *withdrawal* (W) are shown in Figure 10 (N = 836). The D/F/W rate calculated from this table was 15%.

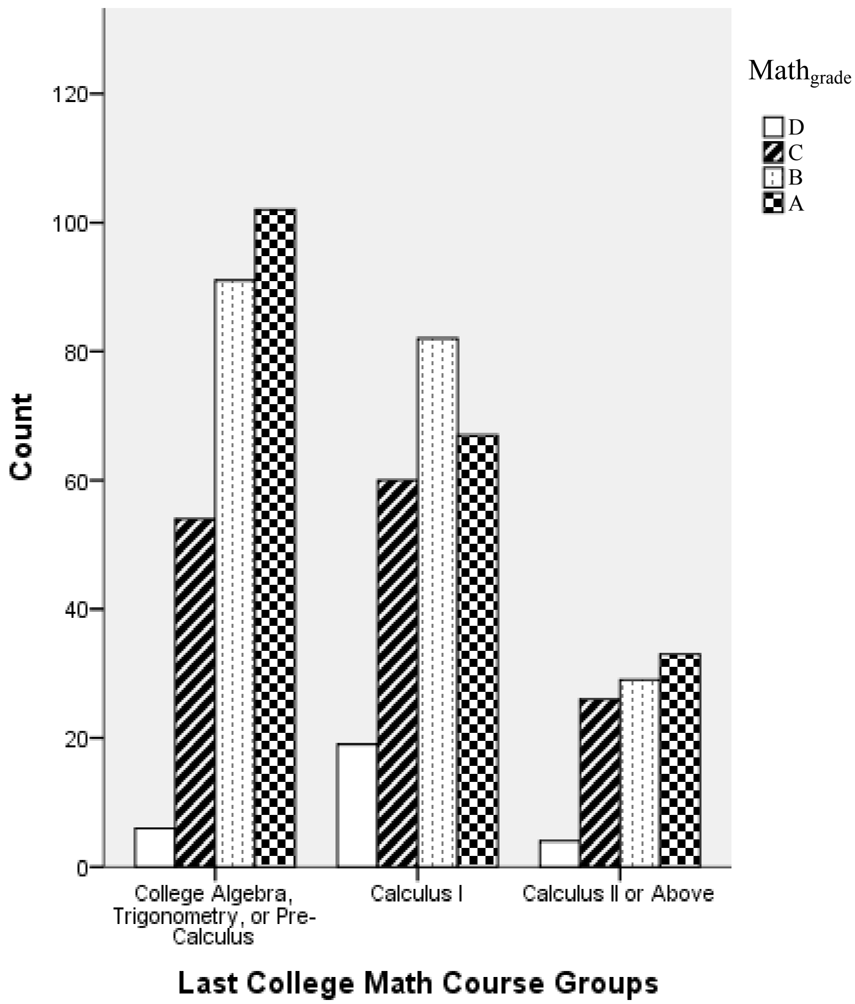
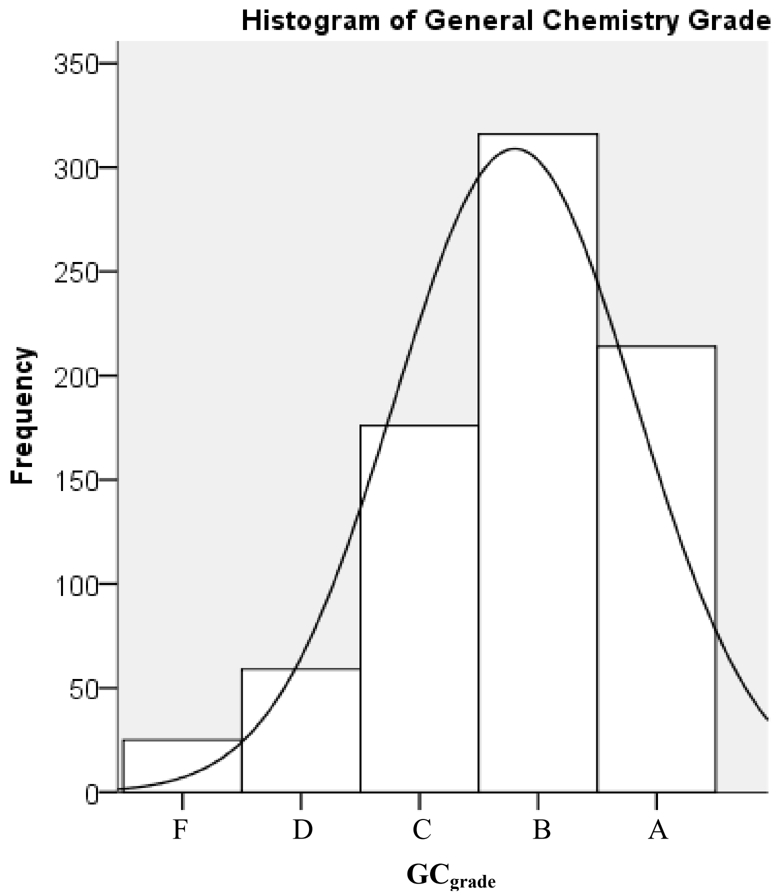


Figure 9 Displays a bar graph illustrating the distribution of A to D grades obtained in the three categories of Math$_{last}$.



Mean = 2.8
Standard Deviation = 1.02
n = 790
Skewness -0.743
Kurtosis 0.155

GC_{grade}	Percent of All Students Enrolled in Labs (n = 836)
A	25.6
B	37.8
C	21.1
CR	0.36
D	7.1
F	3.0
NC	0.24
W	4.9

Figure 10. Upper: Histogram of the A – F grade distribution in general chemistry in the fall of 2005. The percent of the class (n = 790) earning a particular grade is shown on the bar for that grade. Lower: Distribution of all grades earned in general chemistry in the fall of 2005.

Results and Discussion of Statistical Analyses Examining Relationships

Between Background Variables and Course Grades

Was the prerequisite of being calculus-ready in order to enroll in general chemistry an appropriate one? Students were considered *calculus-ready* at KU if they had an ACT_{math} score of 26 or above or if they had credit for college algebra or pre-calculus. Therefore, the ACT_{math} variable and the $Math_{college}$ variable were combined to create the variable called $Calculus_{ready}$ with the following levels:

(1) Not calculus-ready by either criteria

(2) Calculus-ready by coursework criteria only

(3) Calculus-ready by ACT_{math} criteria only

(4) Calculus-ready by both criteria.

Using analysis of variance (ANOVA), the mean GC_{grades} for each of the $Calculus_{ready}$ categories were compared to determine whether any statistically significant differences existed between the groups. Students who were not considered calculus-ready had a mean GC_{grade} of 2.5 (SD = 1.07, n = 73); students who were calculus-ready due to coursework only had a mean GC_{grade} of 2.4 (SD = 1.03, n = 280); students who were calculus-ready only due to the ACT_{math} criteria had a mean GC_{grade} of 3.1 (SD = 0.91, n = 210); and students who were calculus-ready due to both criteria had a mean GC_{grade} of 3.1 (SD = 0.87, n = 227). To determine whether each dependent variables met the ANOVA assumption of equal variance across levels of the independent variable (homogeneity of variance), a Levene's Test was conducted. A significant Levene's test statistic indicates a lack of homogeneity of variance for the dependent variable across the levels of the independent variable (Manly, 2005; Myers & Well, 2003). For the comparisons reported here, the Levene's test was significant - the assumption of homogeneity of variance across the $Calculus_{ready}$ categories was not satisfied. When homogeneity of variance is absent between categories in a comparison, a modified F-statistic, such as the Welch F-statistic, can be used to determine the significance of any differences resulting from the comparison. The distribution of the Welch F-statistic is similar to the typical F-statistic distribution; however, it is a more robust test that is valid when variances are not equal but population distributions are normal. The Welch F-statistic uses a corrected (reduced) value for the degrees of freedom when determining the significance of the F-test (Field, 2009; Manly, 2005). For this analysis, the ANOVA based on the Welch F-statistic was significant, F (3, 276.9) = 34.8, $p < .001$. Post-hoc follow-up comparisons using the Dunnett C correction for unequal variance (Myers & Well, 2003) showed that the categories of $\text{Calculus}_{\text{ready}}$ containing ACT_{math} as a requirement (calculus-ready by ACT_{math} only and calculus-ready by both criteria) differed from the categories that did not contain ACT_{math} as a requirement (not calculus-ready and calculus-ready by coursework criteria only). Therefore, while the not calculus-ready and calculus-ready by coursework only groups had mean letter grades around a C+ and did not differ from each other, they each differed significantly from the calculus-ready by ACT_{math} criteria only and calculus-ready by both criteria groups that had a mean letter grade of B. It should also be noted that the calculus-ready by ACT_{math} criteria only group did not differ significantly from the calculus-ready by both criteria group.

These results suggest that students with ACT_{math} scores above 26 perform significantly better in the general chemistry course, averaging seven-tenths of a letter grade better in the course, and that college-level math coursework in either calculus, pre-calculus, or college algebra does ***not*** improve performance in this course. Based on this, the prerequisite of being calculus-ready, in general, does not seem appropriate for this course since it can be met through two separate pathways, ACT_{math} score or coursework, but only one of these pathways actually significantly benefits student performance in the course. For those students without ACT_{math} scores or those with ACT_{math} scores below 26, some other math placement exam or chemistry placement exam may be a more appropriate determinant of readiness to enroll in general chemistry at KU.

Predicting GC_{grade} from Background Variables

Which demographic and academic background variables are related to student performance in general chemistry, and to what degree can these background variables be combined to predict course performance? A multiple linear regression (MLR) analysis was conducted to determine the predictive ability of students' demographic and academic background variables on their GC_{grade}. First, the creation of scatterplots of each of the interval-level background variables with GC_{grade}, as well as with each of the other interval-level variables, confirmed the linear nature of the relationships between the interval-level variables: HSGPA, $ACT_{composite}$, ACT_{math}, $Math_{grade}$, UGPA, and $\Delta Years_{entry}$. For each of the categorical-level variables with more than two categories, *dummy* variables were created to for each of the categories. The dummy variables were dichotomous in nature and allowed the categories to be used in meaningful ways in later correlation and regression analyses. To create the dummy variables, separate, new variables were generated for each level/group of a categorical variable, and each student was assigned a value of 0 (not a member) or 1 (member) based on the student's membership to the group in question.

Correlational coefficients were calculated between GC_{grade} and each of the interval- and dichotomous-level background variables to understand the strength and significance of their relationships (see Table 4). Of the 28 background variables shown in Table 4, GC_{grade} correlated significantly with 21 of them. All of the interval-level background variables related to prior academic performance exhibited moderate to strong statistically significant Pearson product-moment correlation coefficients , r, with GC_{grade}, ranging from $r = .41$ to $r = .51$ ($p < .01$). All significant correlations between GC_{grade} and the dichotomous background variables were small in strength, ranging from $r = .07$ to $r = .23$ ($p < .05$). This analysis uses the following guidelines for the strength of correlation coefficients: weak = $|r| < .30$, moderate = $.30 < |r| < .50$, strong = $.50 < |r| < 1.0$.

Table 4

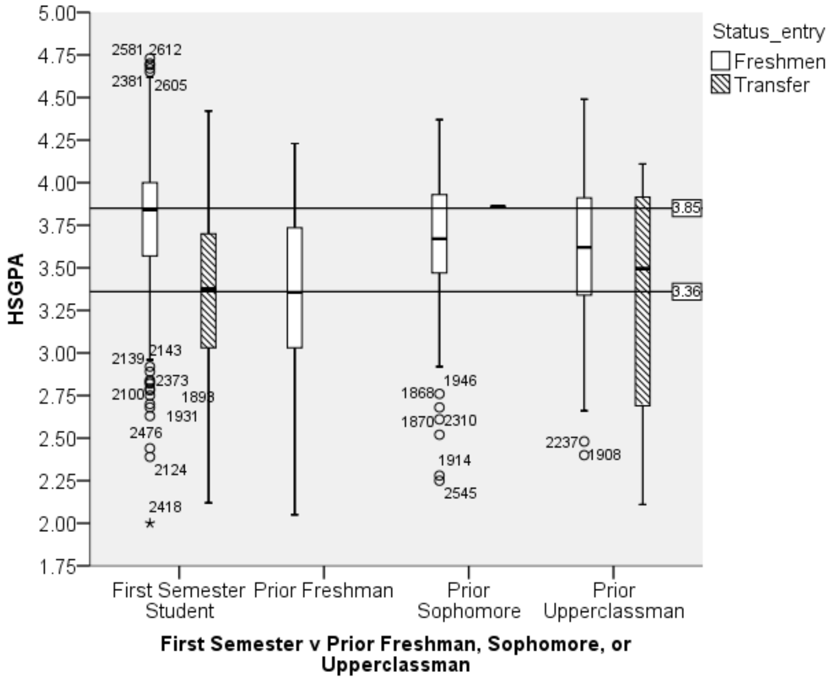
Bivariate and Partial Correlations of Background Variables with GC_{grade} for Fall 2005

Background Variables		Bivariate Correlations GC_{grade} (unless indicated, n = 790)	p	Partial Correlations GC_{grade} (unless indicated, df = 673)	p
HSGPA (n = 713)	r	.45**	.000	Effects Partialed Out	
ACT_{math} (n = 689)	r	.42**	.000	Effects Partialed Out	
UGPA (n = 335)	r	.51**	.000	Removed from analysis	
$Math_{grade}$ (n = 509)	r	.45**	.000	Removed from analysis	
$ACT_{composite}$ (n = 689) (df = 673)	r	.41**	.000	.08*	.038
$\Delta Years_{entry}$	r	-.13**	.000	.02	.693
Female	r	.04	.310	.03	.432
African American	r	-.10**	.006	-.05	.174
Asian	r	.09*	.012	.09*	.025
Caucasian	r	.05	.207	.01	.903
Hispanic	r	-.01	.776	.01	.767
Other Ethnicity	r	-.08*	.033	-.05	.181
Level = Freshman	r	.09*	.012	-.014	.714
Level = Sophomore	r	-.07	.055	-.003	.933
Level = Junior	r	-.09*	.014	-.03	.477
Level = Senior	r	.07*	.044	.09*	.019
$Status_{entry}$= Freshman	r	.20**	.000	.10**	.007
$Status_{entry}$= Transfer	r	-.18**	.000	-.09*	.023
$Status_{entry}$= Other	r	-.08*	.022	-.04	.254
$Math_{college}$ = None	r	.12**	.001	.04	.366
$Math_{college}$ = College Algebra	r	-.20**	.000	-.06	.103
$Math_{college}$ = Calculus I	r	.00	.998	.01	.856t
$Math_{college}$ = Calculus II and Above	r	.11**	.003	.03	.484
$Status_{enrolled}$ = First Semester Freshman	r	.23**	.000	.07	.090
$Status_{enrolled}$ = First Semester Transfer	r	-.16**	.000	-.08*	.049
$Status_{enrolled}$ = Prior Freshman	r	-.20**	.000	-.13**	.001
$Status_{enrolled}$ = Prior Sophomore	r	-.04	.217	.03	.423
$Status_{enrolled}$ = Prior Junior or Senior	r	.001	.902	.06	.111

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Two of the strongest correlation coefficients for GC_{grade} occurred with UGPA ($r = .51$) and $Math_{grade}$ ($r = .45$) (Table 4). However, both of these variables only existed for small subsets (less than 65%) of the enrolled students; they included either students previously enrolled at KU or students who earned a grade for a college-level math course either during college or through advanced coursework in high school. Because the largest portion of students enrolled in general chemistry were first semester freshmen and this group of students were not well represented by the UGPA and $Math_{grade}$ variables, these two variables were removed from further analyses. Of the remaining significant correlations, the strongest were with HSGPA ($r = .45$, present for 90% of the sample), ACT_{math} ($r = .42$, present for 87% of the sample), and $ACT_{composite}$ ($r = .41$, present for 87% of the sample).

While gender did not correlate significantly with GC_{grade}, several ethnicity categories, including African American, Asian, and Other ethnicity, did exhibit significant weak correlation coefficients with GC_{grade}. Most of the dichotomous variables related to academic level also possessed significant weak correlations with GC_{grade}. With the exception of $Level_{enrolled}$ = Senior, any significant correlations with GC_{grade} by variables representing students who were not enrolled in general chemistry as first-semester freshmen displayed a negative relationships with GC_{grade}. The boxplots for HSGPA and ACT_{math} shown in Figure 11 illustrate the degree to which means for the categories of $Status_{enrolled}$ differ by each level of $Status_{entry}$ (Freshman versus Transfer). For both HSGPA and ACT_{math}, First Semester Freshman display distinctly greater means than all other levels, most notably different are the means of transfer students and prior freshmen. Finally, most of the $Math_{college}$ variables related significantly with GC_{grade}. Having no college math (representative of students coming directly from high school and upperclassmen who placed into calculus I or above in college due to standardized test scores or AP/IB credit) or having completed calculus II shared significant positive correlations with GC_{grade} while completing college algebra, trigonometry, or pre-calculus in college shared a negative correlation with GC_{grade}. Completing calculus I in college did not correlate significantly with GC_{grade}, which is somewhat surprising since being calculus-ready is the prerequisite for the course.



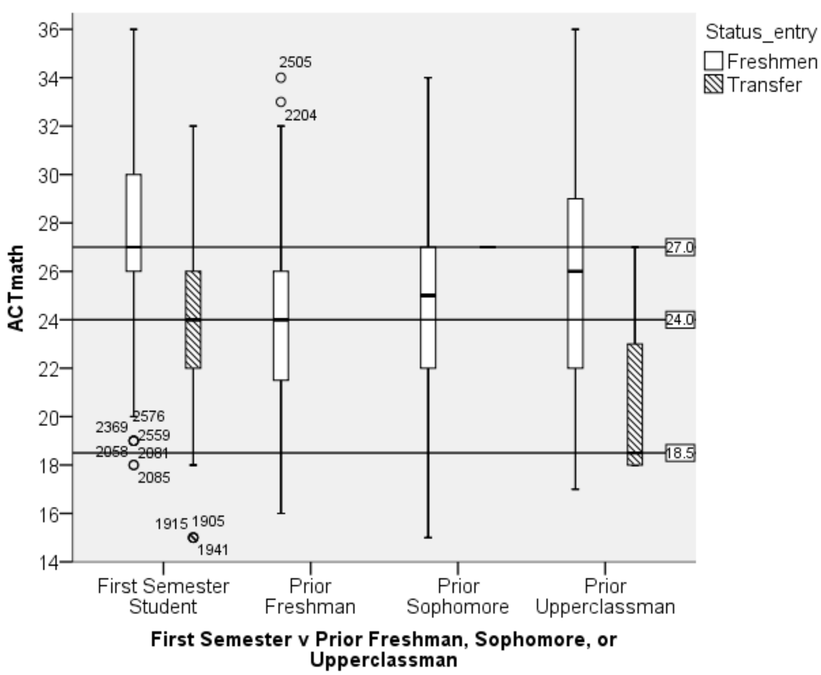


Figure 11[Top] Displays a boxplot comparing the mean HSGPA values for each $Status_{enrolled}$ category separately for students with a $Status_{entry}$ value of either Freshmen or Transfer. The bottom line of each box indicate the value for the lower quartile, and the top line indicates the value for the upper quartile. [Bottom] Displays a boxplot comparing the mean ACT_{math} values for each $Status_{enrolled}$ category separately for students with a $Status_{entry}$ value of either Freshmen or Transfer. The bottom line of each box indicate the value for the lower quartile, and the top line indicates the value for the upper quartile.

Prior research in chemical education has shown that HSGPA and ACT_{math} scores are typically good predictors of GC_{grade}, and the correlations shown in the first columns of Table 4 support the predictive ability of HSGPA and ACT_{math} on GC_{grade} in this study. There existed a high likelihood that many of the other predictor variables also correlated significantly with HSGPA and ACT_{math} since these two variables took very different values in the boxplots for combinations of $Status_{entry}$ and $Status_{enrolled}$ (Figure 11). To determine the impact of other predictor variables on GC_{grade} when the effects of HSGPA and ACT_{math} were removed, partial correlations were calculated between these other variables and GC_{grade}, partialing out the effects of HSGPA and ACT_{math} (second set of columns in Table 4). Of the remaining 24 background variables, only seven remained significantly correlated with GC_{grade} once the effects of HSGPA and ACT_{math} were removed; these included $ACT_{composite}$, Ethnicity = Asian, $Level_{enrolled}$ = Senior, $Status_{entry}$ = Freshman, $Status_{entry}$ = Transfer, $Status_{enrolled}$ = First Semester Transfer, and $Status_{enrolled}$ = Prior Freshman. All of these significant correlations were weak in strength, ranging from $r = .08$ to $r = .13$ ($p < .05$).

Before entering the variables that correlated significantly with GC_{grade} into the MLR model, the bivariate correlations between each of these variables were examined for any strong internal correlations (Table 5). Correlation coefficients of $r = .60$ and above between variables in a MLR analysis could represent sources of multi-collinearity, indicating an increased likelihood that the two variables are measuring the same attribute or theoretical construct. The presence of multi-collinearity between predictor variables in a MLR analysis increases the standard error in the resulting equation. Therefore, to avoid an increase in error associated with multi-collinearity, one of the variables needed to be removed from the model (Myers & Well, 2003). In this study, to decrease the likelihood of multi-collinearity with so many predictor variables present, any pair with $r > .50$ was examined. The decision of which variable from such a pair to remove from further analyses depended on the size of the correlation coefficient exhibited by each variable with GC_{grade} and how each variable would affect the interpretability of the resulting MLR equation.

Table 5

Bivariate Correlations Between Background Variables Significantly Correlated with GC_{grade}

N = 677	HSGPA	ACT_{math}	$ACT_{composite}$	Asian	Level = Senior	$Status_{entry}$ = Fresh.	$Status_{entry}$ = Trans.	$Status_{enrolled}$ = First Sem. Trans.	$Status_{enrolled}$ = Prior Fresh.
HSGPA	—	.46** .000	.46** .000	.07 .064	.03 .469	.16** .000	-.15** .000	-.15** .000	-.18** .000
ACT_{math}			.81** .000	-.03 .468	-.07 .075	.17** .000	-.15** .000	-.13** .001	-.14** .000
$ACT_{composite}$				-.05 .234	-.03 .494	.15** .000	-.15** .000	-.14** .000	-.13** .000
Asian					.04 .366	.07 .091	-.05 .164	-.05 .212	-.02 .573
Level = Senior						-.06 .139	.08* .028	-.04 .365	-.051 .186
$Status_{entry}$ = Fresh.							-.83** .000	-.74** .000	-.01 .821
$Status_{entry}$ = Trans.								.90** .000	-.07 .091
$Status_{enrolled}$ = Prior Fresh.									-.06 .130

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

The two greatest correlational coefficients presented in Table 5 existed between $Status_{entry}$ = Transfer and both $Status_{entry}$ = Freshman (r = .90) and $Status_{enrolled}$ = First Semester Transfer (r = -.83). As shown in Table 4, each of these three variables displayed partial correlation coefficients of similar magnitude with GC_{grade} ($|r|$ = .08 – .10). Therefore, considering the interpretability of the future MLR equation, only $Status_{entry}$ = Transfer was selected for inclusion in further analyses because it described a larger subset of students than $Status_{enrolled}$ = First Semester Transfer but not the majority of the students as $Status_{entry}$ = Freshman did. Thus, a MLR equation including $Status_{entry}$ = Transfer has $Status_{entry}$ = Freshman as its reference group and then includes a correction to the predicted GC_{grade} for students who began as transfer students.

The third greatest correlation coefficient in Table 5 existed between ACT_{math} and $ACT_{composite}$, $r = .80$. Both shared similar correlational coefficients with GC_{grade} ($r = .41$-$.42$), but $ACT_{composite}$ was selected for removal because it more likely reflected a theoretical construct similar to HSGPA. ACT_{math} was more likely to be describing a different attribute of the students in this study. Based on these decisions the following six variables were selected for the MLR analysis: HSGPA, ACT_{math}, Asian, $Level_{enrolled}$ = Senior, $Status_{entry}$ = Transfer, and $Status_{enrolled}$ = Prior Freshman.

Before including HSGPA and ACT_{math} in the MLR analysis, these two variables were *centered* by subtracting their mean value for all enrolled students from each individual student's HSGPA (M = 3.65, SD = 0.452, and n = 713) and ACT_{math} score (M = 26.3, SD = 4.16, n = 689). Centering did not change the resulting regression coefficients or predictor coefficients from a MLR analysis but did reduce the likelihood of multicollinearity existing between predictor variables within the regression analysis (Kleinbaum, Krupper, & Muller, 2008). In addition, centering the interval-level predictors results in an intercept-value for the resulting equation that is easier and more meaningful to interpret. Because, when set to zero, the centered predictor variables ($_{centered}$HSGPA and $_{centered}ACT_{math}$) represent the mean HSGPA and ACT_{math} score for students in the course, the resulting intercept value is the mean $_{predicted}GC_{grade}$ for any students who have the mean value for both HSGPA and ACT_{math}.

All background variables were entered into the MLR at the same time. The descriptive statistics from the resulting MLR analysis are shown at the top of Figure 12. Because the MLR analysis only contained students who reported both a HSGPA and an ACT_{math} score, it reflected approximately 86% of the enrolled students (n = 677). Because HSGPA and ACT_{math} were centered for all enrolled students who reported each value, the mean of $_{centered}$HSGPA and $_{centered}ACT_{math}$ for this sample of only those students reporting both values was not exactly zero (see the *Descriptive Statistics* chart at the top of Figure 12). The mean GC_{grade} earned by students in this model was 2.86 (SD = .995), slightly above the mean for all students in the sample. Because students with $Status_{entry}$ = Transfer were admitted based on completing a minimum of 24 credit-hours at another institution of higher education, they are not required to report HSGPAs or ACT scores; therefore, this model of only students with HSGPAs and ACT scores underrepresents transfer students. Only 34.8% of all of the transfer students earning a grade

Descriptive Statistics

$n = 677$	Mean	Std. Deviation
GC_{grade}	2.86	.995
${}_{centered}HSGPA$	.035	.4408
${}_{centered}ACT_{math}$	.202	4.139
Ethnicity = Asian	.055	.2275
$Level_{enrolled}$ = Senior	.030	.1694
$Status_{entry}$ = Transfer	.047	.2124
$Status_{enrolled}$ = Prior Freshman	.078	.2688

Model Summary[b]

Model	R	R^2	Adj. R^2	*SE* of the Estimate
1	.536[a]	.287	.281	.844

a. Predictors: (Constant), ${}_{centered}HSGPA$, ${}_{centered}ACT_{math}$, Ethnicity = Asian, $Level_{enrolled}$ = Senior , $Status_{entry}$ = Transfer, $Status_{enrolled}$ = Prior Freshman

b. Dependent Variable: GC_{grade}

ANOVA

Model	Sum of Squares	*df*	Mean Square	*F*	*p*
1 Regression	192.2	6	32.033	45.00	.000[a]
Residual	476.9	670	.712		
Total	669.1	676			

Coefficients[a]

Model	Unstd. Coefs. *B*	SE	Std. Coefs. β	*t*	*p*	95.0% CI for B Lower	Upper
1(Constant)	2.86	0.037	--	78.15	.000	2.78	2.93
${}_{centered}HSGPA$	0.673	0.085	0.298	7.97	.000	0.51	0.84
${}_{centered}ACT_{math}$	0.061	0.009	0.253	6.80	.000	.043	.078
Ethnicity = Asian	0.286	0.144	0.065	1.99	.047	.004	.568
$Level_{enrolled}$ = Senior	0.128	0.193	0.022	0.663	.508	-0.25	0.51
$Status_{entry}$ = Transfer	-0.315	0.157	-0.067	-2.01	.045	-0.62	-0.01
$Status_{enrolled}$ = Prior Freshman	-0.506	0.124	-0.137	-4.09	.000	-0.75	-0.26

a. Dependent Variable: GC_{grade}

Figure 12. Output from MLR analysis for 2005.

of A to F in the course are included in this model (n = 32 out of n = 92) compared to 93.6% of those students with Status_{entry} = Freshman (n = 631 out of n = 674).

The multiple correlation coefficient (R^2) and the adjusted multiple correlation coefficient, (adj. R^2) can be seen in the *Model Summary* section of Figure 12. The adj. R^2 takes into consideration the number of predictor terms in the model. According to the adj. R^2 in Figure 12, this model accounted for over 28% of the variance in GC_{grade}. The *ANOVA* table in the middle of Figure 12 indicates that the regression equation resulting from this model significantly explained the variance in a student's GC_{grade}, $p < .001$.

The *Coefficients* section displayed at the bottom of Figure 12 shows the unstandardized coefficient (B) and the standardized coefficient (β) for each variable, the t-statistic and the significance (p) of that variable to the resulting equation, and the lower and upper boundaries for the 95% confidence interval for each of the unstandardized coefficients. According to the significance values, each of the predictor variables, except $\text{Level}_{enrolled}$ = Senior, accounted for some significantly unique portion of the total explained variance ($p < .05$). Based on its non-significant t-statistic, the presence of $\text{Level}_{enrolled}$ = Senior did not add to the explanatory nature of the resulting equation. While the unstandardized coefficients defined the change in a students' ${}_{predicted}\text{GC}_{grade}$ based on a one-unit change for each variable on that variable's original scale, the standardized coefficients converted all variables to the same scale to show the relative impact of each on the resulting equation. Based on the standardized coefficients in Figure 12, HSGPA and ACT_{math} have the largest impacts on ${}_{predicted}\text{GC}_{grade}$. They both have βs that are roughly twice as powerful in the analysis as the next largest β resulting from $\text{Status}_{enrolled}$ = Prior Freshman. The equation resulting from this MLR analysis is shown in Equation 1.

$$\begin{aligned} {}_{predicted}\text{GC}_{grade} = \; & 2.86 + 0.67 * {}_{centered}\text{HSGPA} + 0.061 * {}_{centered}\text{ACT}_{math} \\ & + 0.29 * \text{Asian} + 0.13 * \text{Senior} - 0.32 * \text{Transfer} \\ & - 0.51 * \text{Prior Freshman} \end{aligned} \tag{1}$$

Based on the MLR equation given above, the mean $_{predicted}GC_{grade}$ for a student with the class's mean HSGPA value ($_{centered}HSGPA = 0$) and mean ACT_{math} value ($_{centered}ACT_{math} = 0$) whose ethnicity was not Asian (Asian = 0), $Level_{enrolled}$ was not Senior (Senior = 0), $Status_{entry}$ was not Transfer (Transfer = 0), and $Status_{enrolled}$ was not Prior Freshman (Prior Freshman = 0) was 2.86, above a letter grade of B-. All other variables being equal, a one unit change in HSGPA (for example, comparing a 2.75 HSGPA student to a 3.75 HSGPA student) would produce a two-thirds of a letter grade increase in $_{predicted}GC_{grade}$. When all other variables are equal, a five-point difference in ACT_{math} scores would result in a three-tenths of a letter grade difference in $_{predicted}GC_{grade}$ (5 x 0.06 = 0.30 of a letter grade). The $_{predicted}GC_{grade}$ is nearly three-tenths of a letter grade higher for Asian students and about a one-tenth of a letter grade higher for students taking the course as seniors, but $_{predicted}GC_{grade}$ is about two-thirds of a letter grade lower for transfer students and half of a letter grade lower for students who are still freshmen but have been at the university for a year ($Status_{enrolled}$ = Prior Freshman).

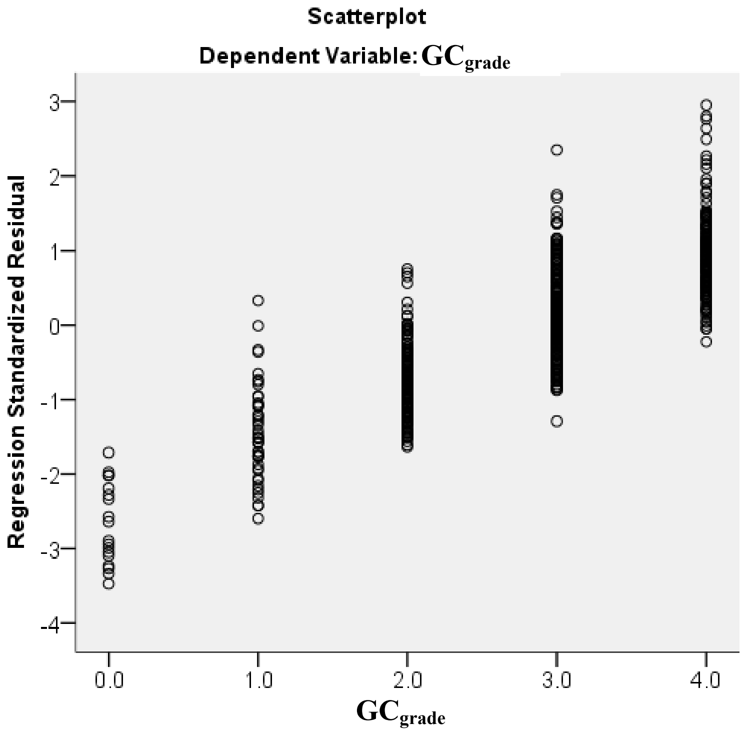
This analysis adheres to all of the assumptions for multiple regressions (Kleinbaum, et al., 2008):

(1) Linearity was confirmed with scatterplots of the criterion with each predictor variable.

(2) Independence was met by the design of the course.

(3) Homoscedasticity, meaning the variance of the residuals is constant for all combinations of the predictor variables, was confirmed by observing a similar spread of residual values at all levels of the predictor variable (see scatterplot in Figure 13).

(4) Normality of the residuals was confirmed by the observation that the distribution of the residuals had a relatively normal shape (see histogram in Figure 13).



Mean = -9.35×10^{-16}
Std. Dev. = 0.996
n = 677

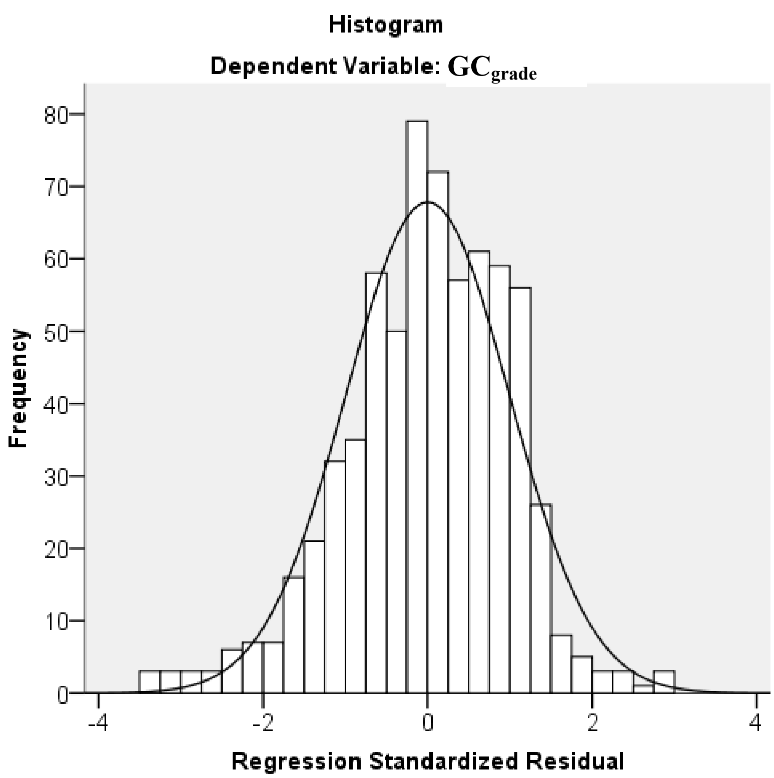


Figure 13 [Top] Scatterplot of GC_{grade} versus the residuals from MLR with GC_{grade} as the criterion. Roughly equal spread (variance) in residual values at each level of GC_{grade} indicates homoscedasticity. [Bottom] Histogram displaying the fairly normal distribution of residuals from MLR with GC_{grade} as the criterion.

Overview of the Student Survey

While the data from university records provided insight into general chemistry students' past performance in high school, in their college level courses, and on standardized exams, it could not provide information about the students' perceptions of the course or their experiences during the course. To explore why some students appeared to continue struggling with introductory math-related chemistry topics near the end of the semester, a survey was designed and administered through WebAssign ® to the general chemistry students during the final two weeks of class. This survey collected self-report data from the students on the following topics: 1) previous high school and college level science and mathematics courses, 2) student actions in chemistry and experience with specific math-related chemistry topics, and 3) student attitudes towards the general chemistry course, its structure, and possible resources (see Appendix A for the full survey). To ensure a sufficient number of students would respond to this survey, the professor awarded five bonus points to student who completed it. Over 70% of the enrolled students supplied answers (n = 621); these students will be referred to as the *survey responders*.

Academic Background Data from Survey

The first questions on the survey dealt with each student's previous high school and college-level math and science courses. Table 6 displays the percent of survey responders who reported that they took each science and math course. Over 95% of the responders reported that they had completed a chemistry course in high school, and over 21% reported taking more than one year of chemistry. Approximately 75% completed a pre-calculus course in high school while just less than 50% completed a calculus course in high school. Over 73% of the responders had taken or were concurrently enrolled in calculus in college.

At the end of this first semester of general chemistry, many of the survey responders planned to continue in chemistry (see Table 7): over 74% planned to take the second semester of general chemistry, 52% planned to take the first semester of organic chemistry, and nearly 45% planned to take

Table 6

Previous Science and Mathematics Courses (*n* = 621)	Yes (%)	No (%)
I took a chemistry course in high school.	95.5	4.5
I got a B or better in my previous chemistry course in high school.	86.5	13.5
I had more than one year in chemistry in high school.	21.5	78.5
I had algebra II in high school.	95.0	5.0
I had trigonometry in high school.	78.7	21.3
I had pre-calculus in high school.	75.0	25.0
I had calculus in high school.	49.7	50.3
I had physics in high school.	75.9	24.1
I have taken or am enrolled in college algebra in college.	55.4	44.6
I have taken or am enrolled in calculus in college.	73.3	26.7
I have taken or am enrolled in physics in college.	30.39	69.61
I have taken or am enrolled in engineering courses in college.	23.1	76.9

the second semester of organic chemistry. However, only 12% or fewer of the responders planned to enroll in analytical, physical, or inorganic chemistry courses. This planned chemistry enrollment pattern is mostly accounted by the large number of students in general chemistry planning to pursue pre-medical professions, which typically require chemistry through the second semester of organic. Table 7 also displays the distributions of majors that students reported to be pursuing. Approximately 11% were pursuing chemistry-related fields (chemistry or chemical and petroleum engineering degrees), over 27% were pursing biology majors (including biochemistry), and over 23% were pursuing other degrees not listed specifically on the survey.

Table 7
Distribution of Future Chemistry Courses and Majors Planned by Survey Responders

Planned Future Chemistry Courses (N = 619)	Portion of Responders (%)
General Chemistry II	74.3
Organic Chemistry I	52.2
Organic Chemistry II	44.9
Analytical Chemistry	7.0
Physical Chemistry	8.9
Inorganic Chemistry	11.6
Other	28.0
Planned Major (N = 621)	**Portion of Responders (%)**
Chemistry	6.0
Chemical & Petroleum Engineering	4.8
Other Engineering	10.8
Biology	27.5
Other Science/Math	4.5
Exercise Science	8.7
Social Science, Business, & Education	10.8
Humanities & Fine Arts	3.7
Other	23.2

Student Actions and Experiences Data from Survey

The survey also contained Likert-scale style questions about student actions and experiences related to chemistry. The scale was constructed with the following levels: 1 = Always, 2 = Very Frequently, 3 = Occasionally, 4 = Rarely, 5 = Very Rarely, and 6 = Never. Table 8 shows the distribution of responses to each of the survey questions related to actions the students took while in general chemistry and what experiences they had with specific math-related chemistry topics. Over 51% of the survey responders reported that they always or very frequently wrote down their units when working a chemistry problem, while, over 72% of responders reported always or very frequently having good problem-solving skills. While the majority of survey responders reported always or very frequently feeling comfortable with the concept of the mole in chemistry, with converting between mass and moles, and with converting between density and moles, approximately 15% - 30% of the responders reported feeling comfortable with these topics only occasionally or less frequently during the semester (21.9%, 15.2%, and 29.4%, respectively). When asked whether they struggled with unit conversions, approximately 44% of responders reported struggling occasionally or more frequently with this topic over the semester. Over 35% reported struggling at these same levels during the semesters with significant figures, and over 50% reported struggling with stoichiometry concepts. When asked about gas law concepts, over 38% responded that they occasionally or more frequently struggled with the topic, and nearly 45% struggled at some level with mole fractions during the semester. Finally, over 68% of responders reported struggling with thermodynamics concepts. The students who continued to feel uncomfortable or continue to struggle with this introductory material at some level over the course of the semester comprise a significant portion of the students in this class. These values seem especially large when recalling that over 95% of the responders reported that they had taken chemistry in high school.

Student Attitudes Towards Math-Related Chemistry Topics and Possible Resources from the Survey

Another set of Likert-scale style questions at the end of the survey asked students what resources they would be interested in having accompany this course, at what points they were interested in the course material, and whether specific changes to the course would lead them to attend class more often. The scale for these questions was constructed with the following levels: 1 = Strongly Disagree, 2 = Disagree Moderately, 3 = Disagree Slightly, 4 = Agree Slightly, 5 = Agree Moderately, and 6 = Strongly Agree. Table 9 shows the distribution of responses for each of these

Table 8
Distribution of Student Responses to Survey Questions about Actions and Experiences in Chemistry

Actions in Chemistry Statements (N = 619 - 621)	Always (%)	Very Frequently (%)	Occasionally (%)	Rarely (%)	Very Rarely (%)	Never (%)
I always write down my units when I work a chemistry problem. (%)	12.7	38.2	34.9	8.7	3.7	1.8
I have good problem solving skills. (%)	17.8	54.9	23.9	2.3	1.0	0.2
I feel comfortable with the concept of a mole in chemistry. (%)	45.6	32.4	16.9	3.9	0.8	0.3
I can convert from mass to moles of a compound. (%)	56.9	27.9	12.1	2.1	0.8	0.2
I can convert from density to moles of a compound. (%)	34.5	36.2	21.1	6.8	1.4	0.0
Experiences with Math-Related Chemistry Topics			(%)			
This semester, I struggled with . . . (N = 620 - 621)	Always	Very Frequently	Occasionally	Rarely	Very Rarely	Never
unit conversions. (%)	2.6	11.1	30.4	16.6	26.9	12.4
significant figures. (%)	2.7	7.2	25.9	20.6	26.7	16.7
stoichiometry concepts. (%)	3.9	14.7	32.0	17.4	20.5	11.6
gas law concepts. (%)	1.6	7.4	29.2	19.8	27.1	14.8
mole fractions. (%)	1.3	10.5	33.2	21.3	22.3	11.5
thermodynamics concepts. (%)	5.3	20.3	42.9	16.8	10.5	4.2

survey questions. Of those responding, over 68% agreed at some level that they would be interested in a web-based math tutorial to accompany the course while over 80% agreed that they would be interested in an accompanying web-based problem-solving tutorial. Over 47% agreed that they would be interested in receiving some type of personal math tutoring along with the course.

When asked about their interest in the course material, over 63% of the responders agreed at some level to being interested in the course at the beginning of the semester when the math-related topics were reviewed. By comparison, over 82% of responders agreed to being interested in the course when chemistry concepts were being covered (Table 9). Over 74% agreed at some level that they were interested when problem solving was covered during lecture. Nearly 30% of the responders agreed to some degree that they would attend class more often if the lectures covered fewer math concepts. However, the majority of responders, nearly 56%, agreed that they would attend class more if the lectures focused more on the chemical concepts at the theoretical level. While attendance was not recorded regularly in this large lecture course, it was estimated that only one-half to two-thirds of the enrolled students attended a typical lecture.

Results and Discussion of Statistical Analyses Examining Relationships Among Student Responses to the Survey Questions

Comparing Survey Attitude and Experience Responses with Calculus-Readiness

Was the group of students who responded that they occasionally or more frequently struggled with math-related topics over the semester composed only of students who had not met the math pre-requisite of being calculus-ready prior to enrolling in general chemistry? A cross-tabulation of student survey responses regarding the math-related chemistry topics and students' *calculus-readiness* was run to answer this question (see Table 10). Without the ability to link responses on this survey to student-specific data from university records, it was not possible to use ACT_{math} and $Math_{college}$ data to determine which students were considered *calculus-ready*. Therefore, for this analysis, each student's

Table 9
Distribution of Student Responses to Survey Questions about the General Chemistry Course

Course Resource Questions *I would be interested in . . .* (N = 621)	Disagree Strongly (%)	Disagree Moderately (%)	Disagree Slightly (%)	Agree Slightly (%)	Agree Moderately (%)	Agree Strongly (%)
a web-based math tutorial to accompany this course. (%)	9.8	11.3	10.5	26.8	21.4	20.3
a web-based problem solving tutorial for this course. (%)	5.3	7.1	6.9	27.2	25.2	28.3
personal math tutoring for this course. (%)	18.3	16.2	18.0	20.4	12.2	14.8

Interest in Course Topic Questions (N = 621)	Disagree Strongly (%)	Disagree Moderately (%)	Disagree Slightly (%)	Agree Slightly (%)	Agree Moderately (%)	Agree Strongly (%)
I was interested at the beginning of the semester when we were reviewing math concepts. (%)	11.6	9.2	15.6	25.2	21.7	16.7
I find this course interesting when we cover chemistry concepts. (%)	4.0	4.2	9.7	29.9	36.7	15.6
I find this course interesting when we cover problem-solving concepts. (%)	5.1	6.0	14.6	32.8	30.4	11.1

Attendance Changing Questions *I would attend class more if . . .* (N = 621)	Disagree Strongly (%)	Disagree Moderately (%)	Disagree Slightly (%)	Agree Slightly (%)	Agree Moderately (%)	Agree Strongly (%)
fewer math concepts were covered in the lecture. (%)	22.7	22.8	24.9	15.6	8.5	5.5
the lecture focused more on the chemical concepts at the theoretical level. (%)	11.1	10.4	22.6	28.4	17.3	10.3

Table 10

Self-reported Comfort and Frequency of Struggling by Students With Math-Related Topics Separated by Calculus-Readiness				
		Completed/Enrolled in College Calculus?		Percent of those struggling who have met prerequisite
Survey Statement	Student Response	Yes (%)	No (%)	
I **feel comfortable** with the concept of the mole in chemistry (%)	Occasionally or Less Often	14.2	7.7	14.2/21.9=64.8%
	Frequently or Always	59.0	19.3	
I **can** convert from mass to moles of a compound. (%)	Occasionally or Less Often	8.5	6.6	8.5/15.1=56.3%
	Frequently or Always	64.7	20.2	
I **can** convert from density to moles of a compound. (%)	Occasionally or Less Often	18.4	11.0	18.4/29.4=62.5%
	Frequently or Always	54.9	15.8	
I have **struggled** with unit conversions this semester (%)	Occasionally or More Often	29.3	14.8	29.3/44.1=66.4%
	Rarely, Very Rarely, or Never	44.0	11.9	
I have **struggled** with significant figures this semester. (%)	Occasionally or More Often	25.0	11.0	25.0/36.0=69.4%
	Rarely, Very Rarely, or Never	48.3	15.8	
I have **struggled** with stoichiometry this semester. (%)	Occasionally or More Often	32.9	17.7	32.9/50.6=65.0%
	Rarely, Very Rarely, or Never	40.4	9.0	
I have **struggled** with gas laws this semester. (%)	Occasionally or More Often	24.8	13.4	24.8/38.2=64.9%
	Rarely, Very Rarely, or Never	48.4	13.4	
I have **struggled** with mole fractions this semester. (%)	Occasionally or More Often	29.8	15.2	29.8/45.0=66.2%
	Rarely, Very Rarely, or Never	43.4	11.6	
I have **struggled** with thermodynamics this semester. (%)	Occasionally or More Often	47.4	21.1	47.4/68.5=69.2%
	Rarely, Very Rarely, or Never	25.8	5.6	

response to the survey question regarding previous or concurrent enrollment in college calculus was used as evidence of being *calculus-ready*. Because prerequisites for enrolling in calculus at the university were checked, students who reported that they had previously completed calculus or were concurrently enrolled in a calculus course in college were considered *calculus-ready*. While this method of determining which students had met the prerequisite created a conservative estimate of the true value (due to some students who were *calculus-ready* not previously or currently enrolling in a calculus course), a large portion, approximately 73%, of the responding students were considered *calculus-ready*.

Table 10 shows that the group of students who can only occasionally or less frequently convert density to moles is composed of both students who have met the pre-requisite for the course and those who have not; and, a greater percent of responders who indicated that they could only occasionally or less frequently convert density to moles (nearly 63% of that group) had met the *calculus-ready* pre-requisite. While fewer responders (just over a total of 15% of all survey responders) reported that they occasionally or more frequently had problems with converting mass to moles, approximately 56% of these students had met the pre-requisite of being *calculus-ready*. Table 10 also displays the cross-tabulated data of responders for other key chemistry skills. When asked to choose the frequency with which they agreed with the statements regarding struggling with unit conversion and stoichiometry during the semester, over 44% of the responders mentioned that they had struggled with the topic of unit conversions and nearly 50% mentioned that they had struggled with the topic of stoichiometry. Approximately 65% of those who reported struggling to some degree with the topics of unit conversions and stoichiometry were considered *calculus-ready* prior to enrolling in this course. Clearly, the group that reported struggling with the math-related chemistry topics was composed of both those students with and without the stated math prerequisites for the course.

Correlational Analyses of Survey Data

Did students struggle with all topics similarly? The analysis to answer this question began with an examination of scatterplots and correlation tables comparing student-reported frequencies of struggling with each of the six math-related chemistry topics. Student responses to all six of these statements correlated significantly ($p<0.01$) with each other, with mostly medium to large Pearson product-moment correlation coefficients ranging from 0.25 to 0.67 (see Table 11). This indicated that survey responders struggling with one of these topics likely struggled to a similar degree with the other topics.

Was the frequency of struggling with the different topics related to responses regarding possible interventions to accompany the course? Answering this question required the calculation of correlation coefficients between student responses to each of the frequency of struggling questions and the possible intervention questions, including those related to a web-based math tutorial, web-based problem-solving tutorial, and personal math tutoring accompanying the course (Table 12). Each of these correlation coefficients indicated significant positive relationships between the variables ($p < .01$). While the correlations were weak to moderate in strength, ranging from $r = .12$ to .40, higher levels of struggling with a topic were related to higher levels of support for an intervention. For each topic, the correlations between frequency of struggling and support for both a web-based math tutorial and a web-based problem-solving tutorial were nearly equivalent, while correlations between frequency of struggling and support for personal math tutoring to accompany the course were typically stronger. Based on these comparisons, it appeared that students who frequently struggled with topics were likely to desire personal math tutoring more than either of the web-based tutorial options but that students who frequently struggled with topics supported all of the possible interventions to a greater extent than other students did.

Table 11

Correlations Among Responses to Survey Questions Regarding Frequency of Struggling with the Math-Related Chemistry Topics

Struggled with . . .	Unit Conversions	Significant Figures	Stoichiometry	Gas Laws	Mole Fractions	Thermo-dynamics
Unit Conversions	1	.39**	.58**	.50**	.55**	.42**
Significant Figures		1	.31**	.25**	.34**	.25**
Stoichiometry			1	.56**	.67**	.49**
Gas Laws				1	.59**	.53**
Mole Fractions					1	.49**
Thermo-dynamics						1

**. Pearson Correlation is significant at the 0.01 level (2-tailed).

Table 12

Correlations Between Responses to Frequency of Struggling Questions and Possible Course Interventions

	Level of Interest in . . .		
Struggled with . . .	Math Tutorial	Problem Solving Tutorial	Personal Math Tutoring
Unit Conversions	.25**	.25**	.37**
Significant Figures	.12**	.17**	.17**
Stoichiometry	.27**	.26**	.40**
Gas Laws	.21**	.22**	.35**
Mole Fractions	.27**	.25**	.37**
Thermodynamics	.24**	.28**	.34**

**. Pearson Correlation is significant at the 0.01 level (2-tailed).

For the students who took chemistry in high school, which prior chemistry and math experience variables were related to student-perceived frequency of struggling with the math-related chemistry topics and desired interventions? For this question, the sample size was reduced to only those survey responders who reported that they had taken chemistry in high school (n = 593). Correlation coefficients were calculated between each of the frequency of struggling questions and the following prior chemistry and math experience variables (Table 13):

(1) Earned a B or better in high school chemistry,

(2) Took more than one year of high school chemistry,

(3) Took calculus in high school, and

(4) Previously completed or currently enrolled in calculus in college.

Only the two prior math experience variables related to taking calculus in either high school or college were chosen for this analysis because they were the only ones that could be reasonably related to the prerequisite of being *calculus-ready* for the general chemistry course. All correlations shown in Table 13 were negative, signifying that students who had the indicated chemistry or calculus experience were less likely to specify a high frequency of struggling with any of the topics. However, most of the significant correlations presented in Table 13 were weak in strength.

Only half of the frequency of struggling questions correlated significantly with earning a B or better in high school chemistry. However, when it was considered that over 90% of the students who took chemistry in high school reported that they earned a B or better in their high school course, it became clear that this variable was simply a poor discriminator of differences within this group of students. For five of the six math-related chemistry topics, frequency of struggling was significantly correlated with both students who took more than one year of chemistry in high school (22.6% of responders in this analysis) and students who took calculus in high school (51.8% of responders in this analysis). Students who took more than one year of chemistry in high school reported struggling significantly less frequently than students with only one year of high school chemistry, and students who took calculus in high school reported struggling significantly less frequently than students who did not take calculus in high school. The correlation coefficients for these comparisons were of weak to moderate size, $r = -.14$ to $-.30$. Finally, for all six of the topics, the correlations between frequency of struggling and previously taking or concurrently enrolling in calculus in college were significant yet weak. For this analysis, 73% of the survey responders had previously completed or concurrently enrolled in calculus in college, and these students reported struggling significantly less frequently than students not taking calculus in college. For four of the six topics, the correlations between frequency of struggling with a specific topic and students taking calculus either in high school or in college were very similar in magnitude. Unit conversions and significant figures were the two exceptions. Taking calculus in high school had a larger negative correlation coefficient with frequency of struggling with unit conversions, while taking calculus in college had a larger negative correlation with the frequency of struggling with significant figures. While all four of the previous experience variables examined in Table 13 were related to the frequency of struggling variables for at least some of the math-related chemistry topics, only prior or current enrollment in calculus in college was related to the frequency of struggling variable for all six topics.

Weak correlation coefficients similar in magnitude to those seen above were present between the variables indicating student support for possible interventions and the previous experience variables (bottom of Table 13). Earning a B or better in chemistry in high school was only significantly negatively correlated with support for personal math tutoring, indicating that students earning a B or better in their high school chemistry course were significantly less likely to show a high level of support for the idea of personal math tutoring to accompany the course. Students with more than one year of chemistry in high school were significantly less likely to show a high level of support for either the idea of personal math tutoring or a web-based problem-solving tutorial accompanying the course. Only students who took calculus in high school were significantly less likely to support all three possible interventions while students previously or currently enrolled in calculus in college were significantly less likely to support either personal math tutoring or a web-based math tutorial (Table 13).

Table 13

Correlations Between Prior Chemistry and Calculus Experiences with Responses to Survey Questions About Frequency of Struggling and Support for Possible Interventions

	Prior Chemistry and Calculus Experiences			
Struggled with . . .	Earned B or Above in High School Chemistry	Took More than One Year of High School Chemistry	Took Calculus in High School	Completed or Currently Enrolled In Calculus in College
Unit Conversions	-.13**	-.26**	-.26**	-.19**
Significant Figures	-.10*	-.07	-.03	-.10*
Stoichiometry	-.10*	-.30**	-.25**	-.23**
Gas Laws	-.06	-.14**	-.19**	-.20**
Mole Fractions	-.08	-.24**	-.22**	-.21**
Thermodynamics	-.05	-.19**	-.16**	-.16**
Level of Interest in …	Earned B or Above in High School Chemistry	Took More than One Year of High School Chemistry	Took Calculus in High School	Completed or Currently Enrolled In Calculus in College
A Web-based Math Tutorial	-.06	-.07	-.16**	-.08*
A Web-based Problem-Solving Tutorial	-.02	-.09*	-.12**	-.05
Personal Math Tutoring	-.14**	-.14**	-.23**	-.13**

**. Pearson correlation is significant at the 0.01 level (2-tailed).
*. Pearson correlation is significant at the 0.05 level (2-tailed).

T-Tests Examining the Effects of Being Calculus-Ready

By how much did the level of struggling for each topic and level of support for the possible interventions differ between students with previous or concurrent calculus experience and students without calculus experience? Were the differences significant? Meaningful? Independent samples t-tests were needed to determine whether the differences between frequency of struggling and levels of support for an intervention were due to either taking calculus in high school or taking calculus previously or concurrently in college. Table 14 displays the descriptive statistics and *t*-test data for responders with and without calculus in high school for the frequency of struggling and the level of support for a possible intervention questions. Table 15 provides this same information for students with and without previous or concurrent enrollment in calculus in college.

For each of these statements, the group without calculus in high school reported a greater frequency of struggling with the topics and more strongly supported the suggested interventions. The *t*-tests showed that the groups differed significantly on frequency of struggling with unit conversions, stoichiometry, gas laws, mole fractions, and thermodynamics and on level of support for all three possible interventions. It should also be noted here that while a significant difference existed between the groups on the statement about a web-based problem-solving tutorial, the difference was not great because on average both of the groups agreed to some level that they would be interested in this resource. The groups diverged most greatly (half of a unit or more on the Likert-style scale) on the statements regarding struggling with unit conversions, stoichiometry, and mole fractions and on the statement regarding support for personal math tutoring. Taking the average of the mean frequency of struggling values resulted in an average frequency of struggling of 3.4 (more often than rarely) for those without high school calculus and 2.9 (slightly less often than rarely) for those who took high school calculus. Taking the average of the mean levels of support for the interventions resulted in an average level of support for interventions of 4.2 (greater than slightly agree) for students without high school calculus and 3.7 (less than slightly agree) for those with high school calculus. From these findings, it appeared that students without high school calculus felt that they would benefit from additional assistance with some of the fundamental math-related topics in general chemistry and that many students in both groups would be interested in having some form of web-based math and problem-solving tutorial.

When examining differences in the same questions for those students with and without previous or concurrent enrollment in calculus in college, many of the same trends were seen. For each of these statements, the group without calculus in college reported a greater frequency of struggling with the topics and more strongly supported the suggested interventions. The *t*-tests showed that the groups differed significantly on frequency of struggling with all six topics and on level of support for the math tutorial and personal math tutoring interventions. As seen above for support for a problem-solving tutorial, both of the groups agreed to some level that they would be interested in this resource. The groups continued to diverge most greatly (half of a unit or more on the Likert-style scale) on the statements regarding struggling with unit conversions, stoichiometry, and mole fractions and on the statement regarding support for personal math tutoring. Taking the average of the mean frequency of struggling values resulted in an average frequency of struggling of 3.6 (more often than rarely) for those without college calculus and 3.0 (only rarely) for those with calculus in college. Taking the average of the mean levels of support for the interventions resulted in an average level of support for interventions of 4.2 (greater than slightly agree) for students without college calculus and 3.8 (less than slightly agree) for those with college calculus. From these findings, it appeared that students without college calculus felt that they would benefit from additional assistance with some of the fundamental math-related topics in general chemistry and that many students in both groups would be interested in having some form of web-based math and problem-solving tutorial. Regarding whether there is any impact of a prior or current calculus course on a student's frequency of struggling or support for an intervention, it appears that whether students take calculus in high school or college does not make a large difference as long as the student takes a calculus course. Those students with calculus struggled less frequently with the mentioned topics and were less likely to support of the inclusion of a web-based math or problem-solving tutorial to accompany this course. Future research

Table 14

Descriptive Statistics and t-test Results from Comparison of Survey Responders With and Without High School Calculus.

	Students *without* High School Calculus Mean	Students *without* High School Calculus Std. Dev.	Students *with* High School Calculus Mean	Students *with* High School Calculus Std. Dev.	Difference in means
Scale used below: 1=Never/2=Very Rarely/3=Rarely/4=Occasionally/5=Frequently/6=Always					
I have **struggled** with …					
unit conversions.	3.4	1.26	2.7	1.23	**-0.7**
T-test Results[a]	***t* (589) = -6.51**		***p* < .001**		
significant figures.	2.9	1.28	2.8	1.31	-0.1
T-test Results[a]	*t* (589) = -0.62		*p* = .532		
stoichiometry.	3.6	1.23	2.9	1.38	**-0.7**
T-test Results[a]	[b]***t* (587.93) = -6.36**		***p* < .001**		
gas laws.	3.1	1.24	2.7	1.21	-0.4
T-test Results[a]	***t* (588) = -4.64**		***p* < .001**		
mole fractions.	3.4	1.214	2.8	1.200	**-0.6**
T-test Results[a]	***t* (588) = -5.51**		***p* < .001**		
thermodynamics.	4.0	1.091	3.6	1.208	-0.4
T-test Results[a]	[b]***t* (587.98) = -4.07**		***p* < .001**		
Scale used below: 1=Strongly Disagree/2=Inclined to Disagree/3=Slightly Disagree/4=Slightly Agree/5=Inclined to Agree/6=Strongly Agree					
Level of **interest** in …					
web-based **math tutorial** to accompany the course.	4.3	1.49	3.8	1.61	**-0.5**
T-test Results[a]	***t* (589) = -3.974**		***p* < .001**		
web-based **problem-solving** tutorial to accompany the course.	4.6	1.33	4.3	1.47	-0.3
T-test Results[a]	***t* (589) = -2.980**		***p* < .001**		
personal **math tutoring** to accompany this course.	3.7	1.59	3.0	1.67	**-0.7**
T-test Results[a]	***t* (589) = -5.67**		***p* < .001**		

a. *t*-test results shown in **bold** are significant at the $\alpha = .05$ level.
b Due to a significant Levene's test for equality of variances, the t-values reported for this comparison are from an independent samples t-tests that did not assume equal variances.

will examine whether a web-based math and problem-solving tutorial that was created specifically for this course at KU can address the students' needs to additional math content assistance and increased comfort with the math related chemistry topics.

Table 15

Descriptive Statistics and T-test Results from Comparison of Survey Responders With and Without Previous or Current Enrollment in Calculus in College

	Students *without* College Calculus Mean	Students *without* College Calculus Std. Dev.	Students *with* College Calculus Mean	Students *with* College Calculus Std. Dev.	Differ-ences in means
	1=Never/2=Very Rarely/3=Rarely/4=Occasionally/5=Frequently/6=Always				
I have **struggled** with …					
unit conversions	3.5	1.31	2.9	1.29	**-0.6**
T-test Results[a]	***t* (591) = -4.83**		***p* < .001**		
significant figures.	3.1	1.28	2.8	1.29	-0.3
T-test Results[a]	***t* (591) = -2.37**		***p* = .018**		
stoichiometry.	3.8	1.29	3.1	1.32	**-0.7**
T-test Results[a]	***t* (591) = -5.88**		***p* < .001**		
gas laws.	3.3	1.26	2.8	1.21	**-0.5**
T-test Results[a]	***t* (590) = -4.82**		***p* < .001**		
mole fractions.	3.5	1.11	2.9	1.24	**-0.6**
T-test Results[a]	**[b]*t* (316.08) = -5.53**		***p* < .001**		
thermodynamics.	4.1	1.02	3.7	1.20	-0.4
T-test Results[a]	**[b]*t* (330.99) = -4.10**		***p* < .001**		
	1=Strongly Disagree /2=Inclined to Disagree /3=Slightly Disagree /4=Slightly Agree /5=Inclined to Agree /6=Strongly Agree				
Level of **interest** in …					
web-based math tutorial to accompany the course.	4.2	1.46	3.9	1.61	**-0.3**
T-test Results[a]	***t* (591) = -2.03**		***p* = .042**		
web-based problem-solving tutorial to accompany the course.	4.6	1.37	4.4	1.43	-0.2
T-test Results[a]	*t* (591) = -1.27		*p* = .206		
personal math tutoring to accompany this course.	3.7	1.63	3.2	1.67	**-0.5**
T-test Results[a]	***t* (591) = -3.14**		***p* = .002**		

a. *t*-test results shown in **bold** are significant at the $\alpha = .05$ level.
b Due to a significant Levene's test for equality of variances, the t-values reported for this comparison are from an independent samples t-tests that did not assume equal variances.

Conclusion

Conclusions from University Records and Survey Data

The analysis of data collected from university records and the end of semester survey revealed that student math ability, not just prior math coursework, played a significant role in student course performance and student experiences in the general chemistry course. While students with a prior calculus course typically struggled less frequently with the math-related chemistry topics, students taking math courses in college to meet the prerequisite of being *calculus-ready* did not demonstrate a course performance beyond that predicted by their ACT_{math} score. A significant portion of students both with and without a previous calculus course indicated that they continued to struggle with several of the math-related chemistry topics over the semester: 45% occasionally or more frequently struggled with unit conversions and mole fractions, 51% occasionally or more frequently struggled with stoichiometry, and 69% occasionally or more frequently struggled with thermodynamic concepts.

Based on the evidence that students from various math backgrounds reported struggling with the math-related content in the course, it was apparent that student math ability was not acting alone. The MLR analysis confirmed that HSGPA, ethnicity, $Status_{entry}$, and $Status_{enrolled}$ variables also play a role in predicting a student's GC_{grade}. Considering that large portions of the students in the class were continuing to occasionally or more frequently struggle with some introductory math-related chemistry content, it was also apparent that the current method of covering the introductory math-related chemistry content was not meeting the students' needs. The majority of the students responding to the survey agreed to some degree that they would be interested in a web-based math tutorial (65%) or a web-based problem-solving tutorial (81%) to accompany the course.

Changes Introduced in General Chemistry Resulting from Preliminary Study

All of the aspects mentioned above were included when determining possible changes to this course. The course needed to better accommodate the wide variety of student math backgrounds present in it while providing all students with additional opportunities to become more confident with the introductory math-related chemistry topics early in the semester. As a result, the following alterations were made to the general chemistry course for the subsequent fall semester.

(1) The introductory math-related chemistry content from the first four chapters of the text was removed from the lecture.

(2) The web-based math tutorial, ReMATCH (Reviewing Math: A Tutorial for Chemistry with Homework) was created for students to use as a review of this content outside of class (asynchronously) during the first month of the course. Chapter Four of this document provides more details about ReMATCH and its design.

(3) During the first two weeks and the last two weeks of class, students completed pre- and post-course surveys, respectively, regarding their confidence and experiences with different chemistry topics, the course, and ReMATCH.

(4) Course performance and survey data from an experimental group created from students in 14 lab sections of the course, who were required to complete ReMATCH assignments, were compared to the students from the remaining 23 lab sections, the comparison group, to isolate the impact of ReMATCH use. Chapters Six through Ten of this document report on the results of these comparisons.

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Chapter 4

Creation of a Web-Based Math and Problem-Solving Tutorial: ReMATCH

Overview

The literature review examining pedagogies previously implemented by general chemistry instructors to improve students' quantitative problem-solving abilities indicated that none of the previously researched interventions met the needs of students in the KU course. The interventions concerned with problem solving did not focus on more basic math concepts. The interventions concerned with basic math concepts did not focus on the transfer of these skills to chemistry. The interventions concerned with transferring knowledge from other fields to chemistry did not focus on quantitative aspects of problem solving, or they required a redesign of the traditional lecture course. The preliminary study of KU general chemistry students in 2005 showed that a substantial portion reported struggling with introductory math-related chemistry topics near the end of the semester and that the portion that were struggling consisted of two main groups: students lacking basic math skills and students with sufficient math ability experiencing difficulty transferring it to the context of chemistry. The intervention for the KU course had to address both groups of students and had to accommodate the removal of the review of this material from the lecture component of the course.

The intervention created to meet the students' needs was called ReMATCH –Reviewing Math: A Tutorial for Chemistry with Homework. It was designed to cover the math-related content from the first four chapters of the general chemistry textbook at a time when this material was no longer covered in detail in lecture. A complete list of the topics covered in ReMATCH appears in Table 16.

Table 16

List of Math-Related Chemistry Topics Covered in ReMATCH

1	conversion factors	8	converting between grams & moles in reactions
2	scientific notation	9	percent composition
3	rounding & significant figures	10	determining empirical formulas
4	the mole	11	limiting reactants
5	molar mass	12	reaction yields
6	subscripts in chemical formulas	13	molarity & concentration
7	coefficients in chemical reactions		

During the first four weeks of a15-week general chemistry course, students used this asynchronous tutorial as a review of content that they covered in high school chemistry. The development of ReMATCH focused on four main goals:

(1) turning student implicit knowledge into explicit knowledge,

(2) encouraging students to master these fundamental math-related chemistry topics,

(3) encouraging students, if needed, to seek assistance for this course early in the semester, and

(4) shifting the focus of students in the general chemistry lecture during the first weeks of the semester from *reviewing math* to *learning chemistry concepts*.

A screenshot of the mission statement for ReMATCH as it is displayed on the ReMATCH website is shown in Figure 14. The design of ReMATCH addressed the issues experienced by both groups of students struggling with the quantitative problem solving in general chemistry by including four distinct components for each topic:

(1) *Everyday Context Tutorial* – introduces and explains of the concept (or equivalent concept) in everyday context and provides an opportunity for practicing the appropriate math skills in familiar contexts with scaffolded example problems.

(2) *Everyday Practice Problems* – provides an opportunity for practicing the appropriate math skills in familiar contexts with problems that include automated feedback and that have scaffolded solutions available if necessary.

(3) *Chemistry Context Tutorial and Practice Problems* – introduces and explains the concept in the context of chemistry and provides an opportunity for practicing the familiar math skills in a chemistry context with scaffolded example problems.

(4) *Homework Assignment* – provides an opportunity for practicing the appropriate math skills in the chemistry context with homework problems that include automated feedback and allow an unlimited number of attempts.

Table 17 outlines the critical design elements of each of the above sections of ReMATCH. Figure 15 and Figure 16 show screenshots from ReMATCH pages introducing or explaining concepts in an everyday and chemistry context, respectively.

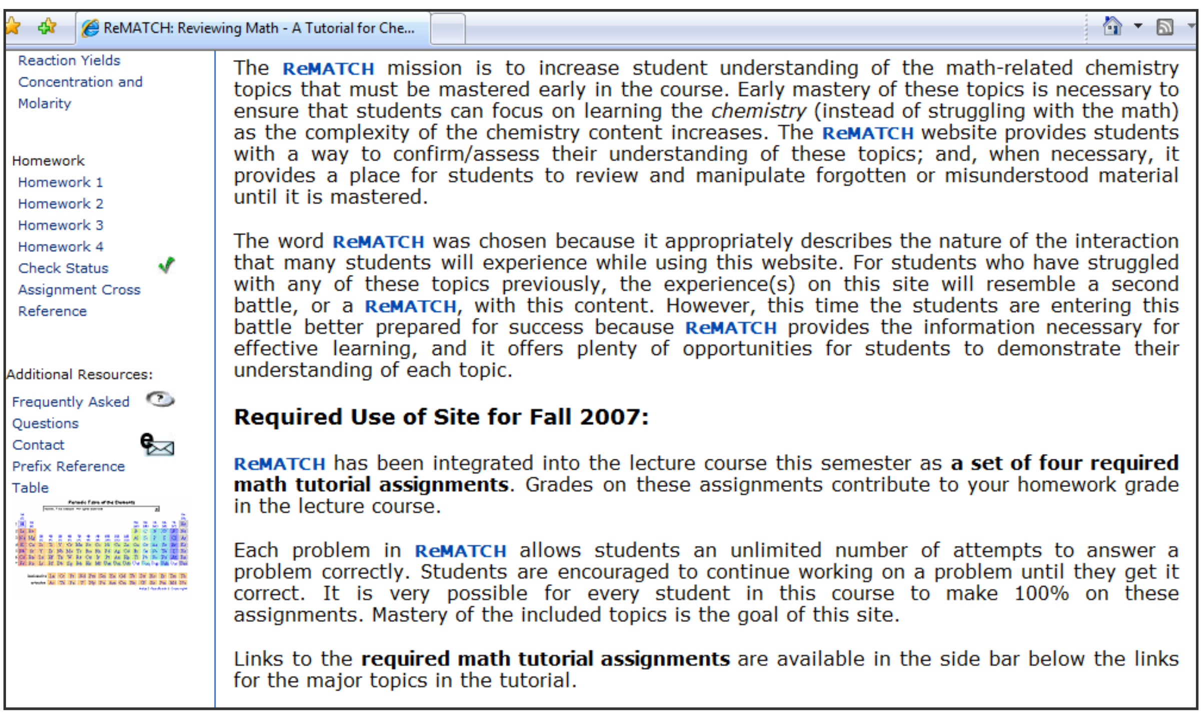
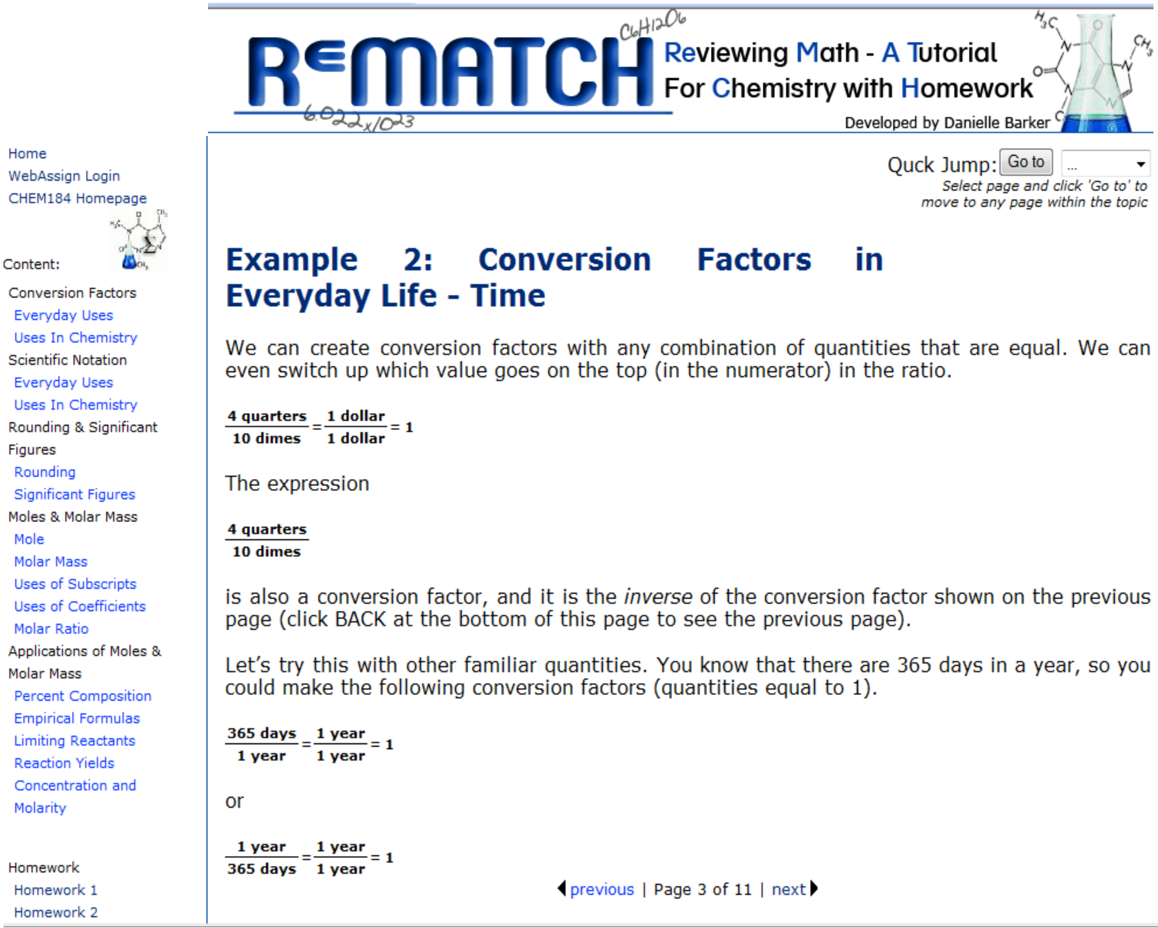


Figure 14. Screen shot of the mission of ReMATCH as displayed on the tutorial homepage.

Table 17

Critical Design Elements for Each Section of ReMATCH	
Everyday Context Tutorial	• Introduces basic math skills and concepts necessary for quantitative problem solving in chemistry • Shows students that they already possess many of the math skills necessary for chemistry problem solving • Encourages students to examine their metacognitive processes when solving familiar problems to become aware of their implicit actions so that the actions become explicitly understood and are transformed to explicit knowledge that students can transfer • Demonstrates the form the familiar problem would take if solved like a chemistry problem • Shows every step in an explanation or worked-example, even those typically left unstated in textbook solutions • Models and clearly identifies expert processes through process-oriented worked examples • Provides structured guidance with problems solving through the use of dimensional analysis to check conceptually-based solutions
Everyday Practice Problems	• Provides students the opportunity to practice and become confident with manipulating familiar quantities using the necessary math skills • Provides students the opportunity to practice and become confident modeling the metacognitive processes associated with expert problem solving in a familiar context • Solutions to these problems are not initially visible • Provides immediate feedback regarding the correctness of an answer that is entered into an answer field to engage students in their practice • Students can select to view scaffolded solutions to these problems if they want to check their problem solving process
Chemistry Context Tutorial and Practice Problems	• Introduces and defines basic math-related chemistry topics • Explicitly discusses how the chemistry topic and its familiar analog are similar, reminds students to recall the related examples and explanations from the everyday contexts, focuses on connections between the everyday and chemistry contexts to aid skill transfer • Models and clearly identifies the expert process necessary to solve the quantitative chemistry problems by providing process-oriented worked examples • Examples problems using chemistry topics demonstrate multiple applications of the topic • Provides practice problems for students to solve prior to checking their solution against a scaffolded solution • Provides structured guidance with problems solving through the use of dimensional analysis to check conceptually-based solutions
Homework Assignment	• Uses a mastery learning approach by allows an unlimited number of attempts to answer each question correctly • Provides multiple applications of math-related chemistry skills/concepts • Provides immediate feedback regarding the correctness of an answer that is entered into an answer field to engage students in their practice • For an incorrect answer, provides information regarding how it is wrong – significant figures, scientific notations, rounding, or other – and suggests common mistakes to look for when review the solution



ReMATCH Reviewing Math - A Tutorial For Chemistry with Homework

Developed by Danielle Barker

Home
WebAssign Login
CHEM184 Homepage

Content:

Conversion Factors
Everyday Uses
Uses In Chemistry
Scientific Notation
Everyday Uses
Uses In Chemistry
Rounding & Significant Figures
Rounding
Significant Figures
Moles & Molar Mass
Mole
Molar Mass
Uses of Subscripts
Uses of Coefficients
Molar Ratio
Applications of Moles & Molar Mass
Percent Composition
Empirical Formulas
Limiting Reactants
Reaction Yields
Concentration and Molarity

Homework
Homework 1
Homework 2

Quck Jump: Go to ...

Select page and click 'Go to' to move to any page within the topic

Example 2: Conversion Factors in Everyday Life - Time

We can create conversion factors with any combination of quantities that are equal. We can even switch up which value goes on the top (in the numerator) in the ratio.

$$\frac{\text{4 quarters}}{\text{10 dimes}} = \frac{\text{1 dollar}}{\text{1 dollar}} = 1$$

The expression

$$\frac{\text{4 quarters}}{\text{10 dimes}}$$

is also a conversion factor, and it is the *inverse* of the conversion factor shown on the previous page (click BACK at the bottom of this page to see the previous page).

Let's try this with other familiar quantities. You know that there are 365 days in a year, so you could make the following conversion factors (quantities equal to 1).

$$\frac{\text{365 days}}{\text{1 year}} = \frac{\text{1 year}}{\text{1 year}} = 1$$

or

$$\frac{\text{1 year}}{\text{365 days}} = \frac{\text{1 year}}{\text{1 year}} = 1$$

previous | Page 3 of 11 | next

Figure 15. Screenshot of a ReMATCH tutorial page that explains several conversion factors that students use with ease in their everyday lives but that many students fail to realize they are manipulating on a daily basis. A portion of the navigation side panel is visible on the left-side of the screen; it allows students to navigate between topics, homework assignments, and available resources (the links to resources are not visible in this image).

End of Page 7 of Conversion Factors in Chemistry:

Now we should try using these conversion factors to solve some problems.

Given the two conversion factors above involving milliliters

$$\frac{\textbf{1 milliliter}}{\textbf{1 centimeter}^3} \textbf{ and } \frac{\textbf{1000 milliliters}}{\textbf{1 liter}}$$

let's work an example.

How many liters are in 350 centimeter^3.

The first piece of information you need to write down is what you were given, in this case this is 350 centimeter^3.
Then, decide which conversion factors you will need.
Finally, arrange the correct conversion factors in the right orientation to solve the problem and end up in the units of liters.

The solution should look like the following.

$$\textbf{350 } \cancel{\textbf{centimeter}^3} \times \frac{\textbf{1 } \cancel{\textbf{milliliter}}}{\textbf{1 } \cancel{\textbf{centimeter}^3}} \times \frac{\textbf{1 liter}}{\textbf{1000 } \cancel{\textbf{milliliters}}} = \textbf{0.350 liters}$$

Now that we have discussed how we can convert between some metric prefixes in chemistry, we need to examine another use of conversion factors in chemistry. ***Conversion factors are also used in chemistry to convert between different kind of units (for example, from units of mass to units of volume), not just different prefixes of the same unit.*** These conversion factors are typically formed from known physical properties of a substance. The property we will examine first is density.

Density, and its usefulness as a conversion factor, are shown on the next page.

Introduction to Significant Figures

Now that rounding has been covered, we need to discuss how a scientist knows how many digits to include when rounding answers and recording measurements.

How do you know the number of digit to which you should round at the end of a calculation?

The decision about rounding to a particular number of digits is based on the limitations of the instruments that were used to collect the measurements that were necessary to perform the calculation. This is referred to as determining the number of **significant figures**. **Significant figures** are called *significant* because they indicate how precise our measurement can be when using a particular instrument (so, the word *significant* here is referring to the precision of the instruments involved).

When we take measurements in chemistry, we can only be as precise as the least precise instrument that we use. An understanding of **significant figures** is necessary to understanding chemistry because use of **significant figures** reflects the fact that when we conduct experiments we are using instrumentation that have limitations in how precisely they can measure a given amount of a compound of interest (each instrument is only *so* sensitive). We rely on **significant figures** to clearly inform others of how precise our measurements are and thus how precise our calculations really are. **Significant figures** gives people an idea of the possible error associated with our findings.

When we report a number to the correct number of **significant figures** ***we include the last digit that we know for certain AND a best estimate of the first uncertain digit***. We estimate the first uncertain digit and include it in the value we record because as humans using these limited instruments we have the ability to make a judgement about the final value we record. To this effect, we are visually able to estimate fairly accurately to one place beyond what is known for certain.

The following illustrations might make this easier to understand.
Please click the link below to see the examples on the next page.

Figure 16. Screenshots of two ReMATCH tutorial pages introducing and explaining topics in a chemistry context.

Integration of Constructivist-Based Pedagogies in ReMATCH

Initial Inspiration: Pienta's Tutorials

To meet the needs of the KU students, a web-based math and problem-solving tutorial, ReMATCH, was created by integrating many of the constructivist-based pedagogical strategies for which the chemical education research literature provided evidence of improved student quantitative problem solving, concept/skill transfer, course performance, metacognitive skills, confidence, or engagement with the course material. When developing the design of this intervention, the most appealing of the previously presented pedagogies was the math- and calculator-skills tutorials implemented by Pienta at the UNC–Chapel Hill and later at the University of Iowa (Pienta, 2003; Pienta, et al., 2001). The web-based and asynchronous nature of these tutorials and their focus on the math skills necessary at the beginning of a general chemistry course were both desirable features. Providing the tutorial asynchronously allows students the time they require to construct their understanding of the concepts and skills – the time to restructure their prior knowledge in a way that allows for the assimilation of related new information – as opposed to lectures, which move through content at a pace chosen by the instructor. According to Bruer (1993a), "[Teachers] must provide the time students need for mental restructuring. Hurrying on to the next lesson or the next topic does not allow for sufficient reflection on the implications of the present lesson." For a chemistry course where students enroll with diverse mathematical and problem-solving backgrounds, it makes sense to present a review of the material outside of lecture and to reserve lecture time for topics more central to the conceptual understanding of chemistry. Covering this introductory material asynchronously via a web-based tutorial allows students to personalize the pace of learning of this material. However, a method has to be in place to encourage less motivated students to use the tutorial and practice their problem-solving skills outside of lecture. This necessity was supported by Pienta's finding that with a voluntary tutorial, roughly half of the students who did not use it would have most likely benefited from some intervention (Pienta, 2003). Therefore, the ReMATCH homework was designed to be a graded feature of the course to be included in either the laboratory grade or lecture grade.

Inspiration from Remedial and Preparatory Courses

Several attributes of the remedial and preparatory courses were incorporated into the design of ReMATCH, including (1) meeting students at their present level of understanding and ability when initially presenting different chemistry and math concepts, (2) providing students with structured guidance regarding how to approach the solving of chemistry problems, and (3) supporting students with their transition to a higher level of math and problem-solving ability. Unlike the remedial and preparatory courses, it was preferred for ReMATCH to accomplish these goals without moving the struggling students to a separate course because the introduction of a preparatory course would most likely extend students' time-to-degree and would require the chemistry department to offer an additional course. To meet a diverse group of students at their individual levels, ReMATCH presents math-related chemistry topics at multiple levels of understanding and then provides students with easy access to the level of content that interests them. Additionally, to engage students at all levels, the text of the tutorial is written in an informal, friendly, and coaching style and voice. When new terms are introduced, they are highlighted and clearly defined. When new chemical concepts are introduced, a familiar analog is presented first and practice problems are provided for students to become confident with interacting with and manipulating this familiar idea. Then, the tutorial defines the new chemical concept and demonstrates very explicitly how it is similar to its more familiar analog. Finally, multiple worked-examples show how the new chemical concept is manipulated and where it can be used via its applications in multiple contexts.

The influence of remedial and preparatory courses on the design of ReMATCH can also be seen in the tutorial's provision of structured guidance for each level of problem-solving ability. The use of dimensional analysis in examples and explanations throughout the tutorial provides a form of structured guidance. Dimensional analysis was selected for this purpose since it focuses on the units associated with quantities and measurements in chemistry. Students notoriously struggle with remembering to include units when solving general chemistry problems because they are much more familiar with solving the mostly unitless problems in their math courses. ReMATCH introduces dimensional analysis as a method for students to use when checking their answers. Dimensional analysis serves as a simple bookkeeping process, allowing students to determine whether the conceptual approach they have followed produces the desired result.

To assist students moving from their original level of problem-solving ability to the level of a successful quantitative problem solver, ReMATCH incorporates significant scaffolding into all example problems and provides a mastery-learning approach. Scaffolding is provided through the use of process-oriented worked examples in ReMATCH tutorial pages. The process-oriented approach appears in the solutions to all example and practice problems. This approach places a strong emphasis on making the normally implicit tasks performed by expert problem solvers explicit and visible to the students. Using this approach, the process-oriented worked examples

(1) model how experts initially restructure a problem,
(2) explicitly state some questions that experts might ask themselves about their own understanding of the question while they are planning a solution,
(3) outline a solution to the problem conceptually,
(4) determine the necessary mathematical relationships and performs the calculations, and
(5) demonstrate a method of checking the resulting answer.

By seeing these expert processes for each problem, students become more aware of their metacognitive processes and can begin to model these expert processes in their own attempts at solving problems. Students are assured plenty of opportunities to practice these expert processes while solving problems because of the mastery approach to learning that ReMATCH delivers. The chemical education research on remedial and preparatory courses indicates that working many problems increases student confidence in their ability (REF). Students are allowed an unlimited number of attempts for each homework problem associated with the tutorial.

Inspiration from Online Homework and Web-Based Worked Examples

After entering a response, students receive immediate feedback regarding its accuracy. According to studies about online homework and web-based worked-examples, immediate feedback helps keep students engaged in the process of problem solving because, (1) if they are informed that they are correct, it improves their confidence with the material, and (2) if they discover they are wrong, it encourages them to consider their problem-solving process for the error. When students answer problems incorrectly in the ReMATCH homework, they are informed whether the response is wrong due to significant figures, scientific notation, orders of magnitude, or other, and they are provided with a list of common pitfalls that should be checked for when attempting to identify the source of an error. Research on web-based worked examples demonstrates that access to worked-examples and metacognitive strategies while solving homework problems increases student performance and self-efficacy with problem solving in chemistry (Crippen & Earl, 2004). Therefore, when students are working homework problems, ReMATCH provides them easy access to the tutorial pages where worked-examples and metacognitive strategies are provided.

Inspiration from Other Tutorials

Research on web-based tutorials relating chemistry to students' everyday lives consistently demonstrates an increased level of student engagement in courses implementing these tutorials. Additionally, research on concept and skill transfer, shows that transfer is more likely to occur when students are familiar with the context and when the similarities between two contexts are explicitly stated. Therefore, to ensure that the general chemistry students are engaged and have the greatest opportunity for concept and skill transfer, ReMATCH initially introduces topics in a context that is familiar to the students – something from everyday life or a typical high school math course. Then, the students are given the opportunity to familiarize themselves with the topic in these familiar conditions by working multiple problems before attempting to transfer this understanding to the context of chemistry. When example problems with these familiar topics are presented, ReMATCH models how an expert chemist might approach solving the problem. Therefore, students see expert metacognitive strategies modeled in familiar contexts as well. Since the context is familiar, this should allow the student to focus on modeling the metacognitive processes and general problem-solving strategies presented. Then, when the chemistry topic is introduced, its similarities to the more familiar topic are explicitly defined, and students are walked through examples with the new chemistry topic. These examples refer students back to how the same or similar procedures were used to solve the more familiar analog. This organization of material that moves from familiar contexts to new contexts ensures that students have relevant prior knowledge and understandings on which to build their new chemistry knowledge.

Inspiration from Cognitive Apprenticeship

As another method of engaging the students in the material presented in the tutorial portion of ReMATCH, the text of the tutorial is written to simulate the support (mentoring, coaching, and scaffolding) provided by a peer-leader in the Peer Led Team Learning instructional strategy arising from the cognitive apprenticeship pedagogies (Tien, et al., 2004). Peer-leaders help students scaffold their learning and remind students to consider the connections between their different pieces of knowledge and to make these connections explicit to the students (e.g. relating a chemistry concept to a more familiar concept) (Tien, et al., 2004). To accomplish this in ReMATCH, the general descriptions and explanations in the tutorial text are written in an informal, friendly, coaching tone and voice. The text asks students to consider their own reasoning patterns and to reflect back on why certain steps were performed when solving different tasks. As an additional similarity to cognitive apprenticeship pedagogy, ReMATCH includes the four types of knowledge that Collins and his colleagues (1987) identified as essential components of cognitive apprenticeship: domain knowledge, expert processes, control strategies, and learning strategies. Table 18 relates how each of these types of expert knowledge are presented in ReMATCH. In light of these similarities, it is clear that ReMATCH is a web-based model of the cognitive apprenticeship instructional strategy that is designed to assist students with their mastery of quantitative problem-solving skills related to introductory math-related chemistry topics.

Table 18

Four Types of Expert Knowledge Present in Cognitive Apprenticeship	Location of Specific Types of Expert Knowledge in ReMATCH
Domain knowledge: vocabulary, syntax, and rules	• Vocabulary is found in the introductions to topics and general explanations provided in tutorial text. • Definitions are provided and highlighted in the tutorial when new terms are introduced. • Rules for using new concepts and skills are discussed in the general explanations in the tutorial text and illustrated in the worked-examples. • The provision of the necessary vocabulary and rules for solving quantitative chemistry problems is vital to meeting students at their current level of understanding of the topics.
Expert processes: problem-solving strategies and heuristics	• Expert processes and general problem-solving strategies are modeled explicitly in the process-oriented worked examples. • Dimensional analysis is provided as a problem-solving strategy for students to use when checking the solution to a problem. • The transfer of knowledge from one domain to another is an expert process that is explicitly demonstrated in the tutorial text. • Mastery approach to learning allows students the opportunity to model these expert processes for themselves.
Control strategies: when and where to apply different strategies	• Various applications for concepts are provided in the general explanations, worked-examples, and practice problems. • Various applications of problem-solving and metacognitive strategies are modeled in the worked-examples and practice problems.
Learning strategies: methods of learning domain knowledge, expert processes, and control strategies	• ReMATCH tutorial pages and homework problems are provided as the learning strategy enabling the acquisition of these other knowledge types.

Logistics of Using ReMATCH

Logging In

Students gain access to the ReMATCH website by following a URL provided in their course syllabus or by clicking on a link to the URL available on the course website. The URL links to the ReMATCH log-in page. For the studies presented here, on a ReMATCH-user's first visit to the website, he/she was requested to enter his/her unique KU identification number into two separate input fields and, then, to click the *First time here!* box. This action created a new entry (row) for the student's unique identifier in the database associated with ReMATCH. All ReMATCH-use data for a particular student was associated with his/her unique identification number in this database. On returning visits, students also had to enter their unique KU identification number in two separate input boxes. The two boxes for this value were required at each log-in to reduce the possibility of students accidentally mistyping their KUID and possibly having their ReMATCH-usage statistics associated with another student's identification number. Figure 17 shows an image of the ReMATCH log-in screen.

Navigation

ReMATCH is intended to be flexible so that students can use it in different ways based on their specific needs. Designed to meet students at their current level, the tutorial provides the information, interconnections, and practice students need to develop their confidence with their math skills so that they can quickly shift their focus away from math-related issues and towards the conceptual chemistry content for the remainder of the course. To aid with the development of connections between these domains within ReMATCH and to keep students engaged in using the tutorial, students can easily navigate between each of the four components for a topic, and they can skip any of the sections or practice problems for topics with which they are already comfortable. Figure 18 shows the navigation side panel included in later versions of ReMATCH, allowing students simply to click on a topic or homework assignment of their choice; a simpler version of this existed in the original edition of

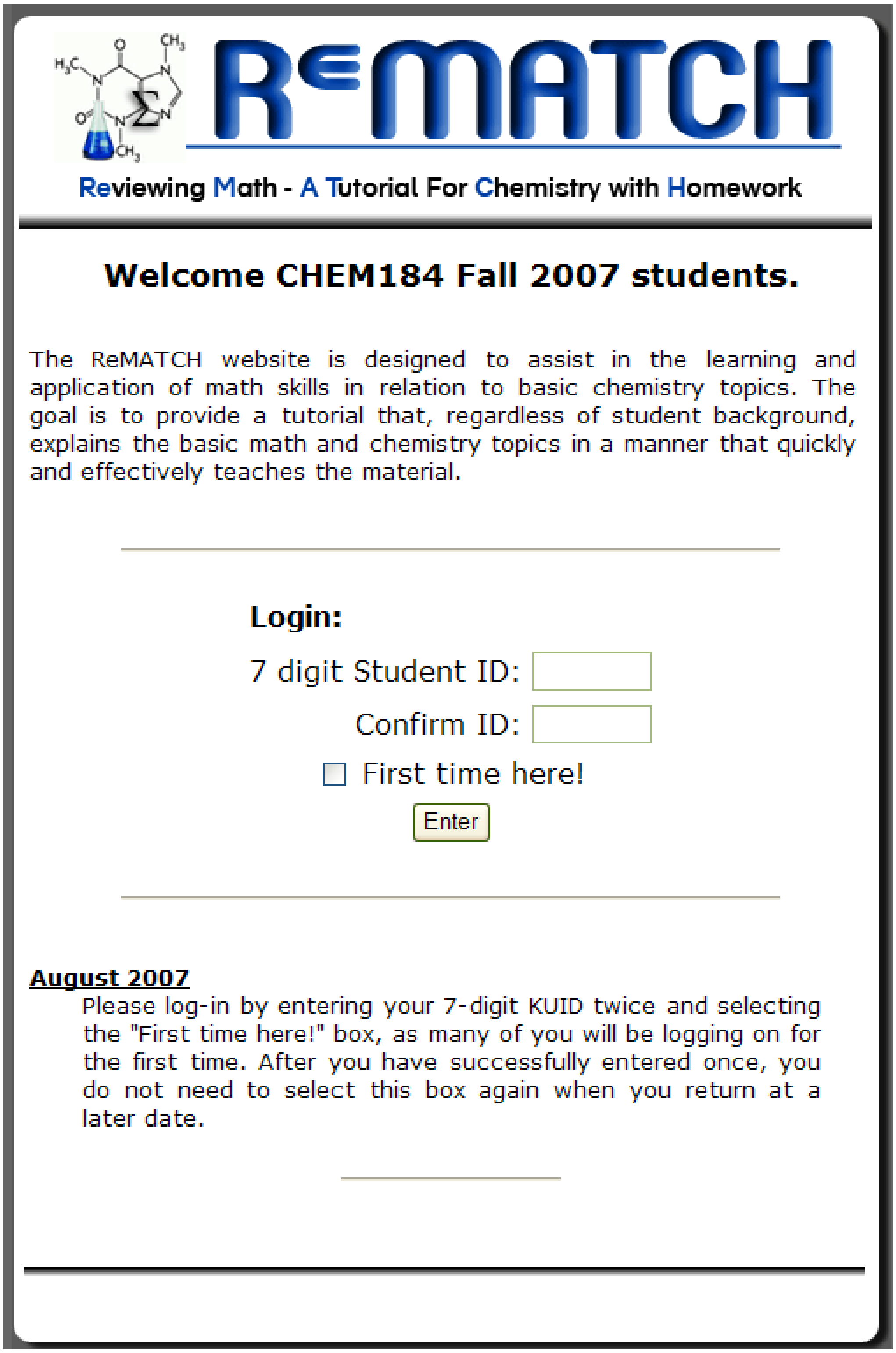


Figure 17 Screenshot of the log-in screen for accessing the ReMATCH tutorial and homework pages

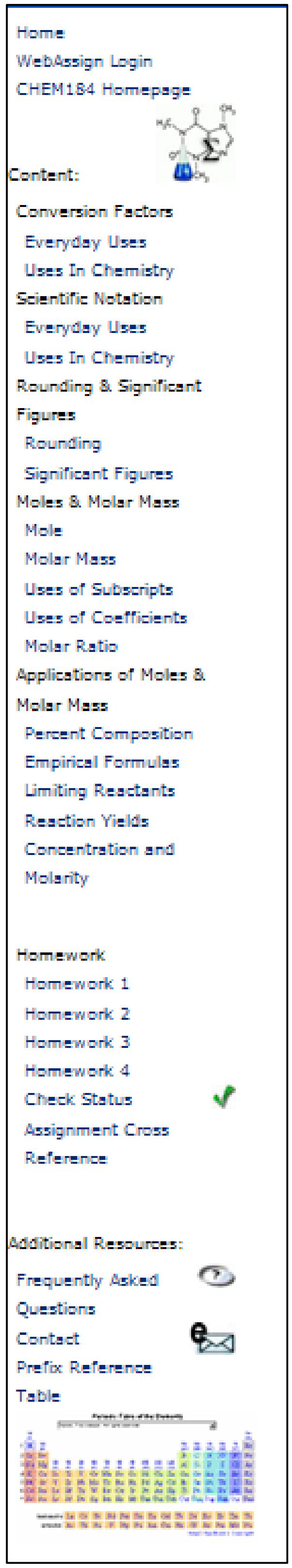


Figure 18 Screenshot of the navigation side panel available on every ReMATCH tutorial and homework page

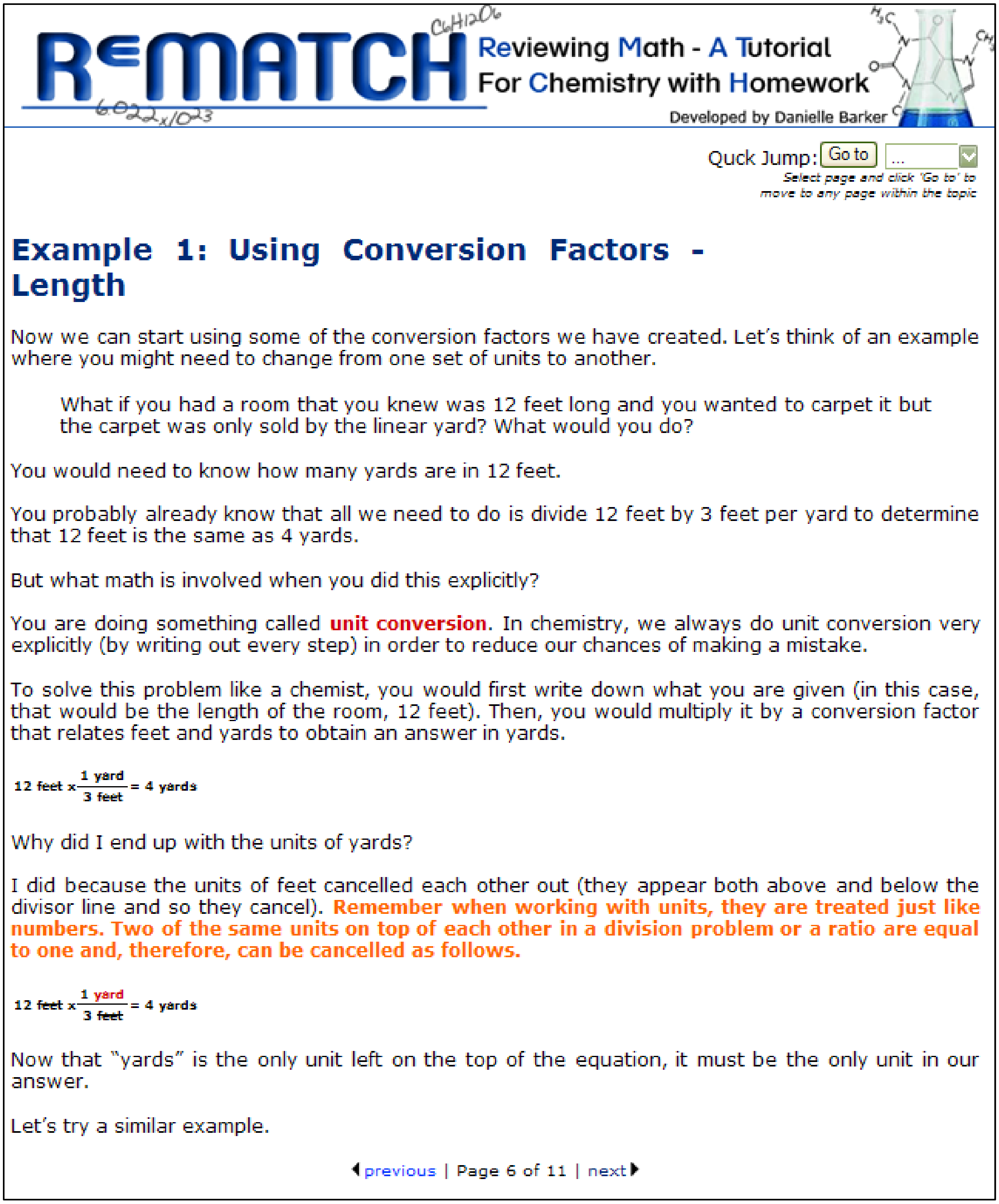
ReMATCH. A *Quick Jump* navigation box (visible at the top of Figure 19) is also included at the top of each tutorial page allowing students to select a specific page within a particular topic and at the top of each homework page allowing students to select a specific homework problem within a particular with the mentioned topics and were less likely to support of the inclusion of a web-based math or homework assignment. Finally, every page also includes navigation buttons (visible at the bottom of Figure 19) allowing students to move one page forward or backward within a topic or homework assignment.

Additional Resources and Links

At the bottom of the navigation side panel, ReMATCH users are provided several resources, including a link to submit questions or comments to the ReMATCH designer and a link to Frequently Asked Questions (FAQ) about the ReMATCH site and homework assignments (Figure 20). Students were encouraged to contact the site designer at any time. The questions posted on the FAQ came from student emails to the ReMATCH designer, and the responses were the ones provided by the designer in emails back to the students. When the same question was seen multiple times, the question and answer were added to this FAQ. These resource links also provide students quick access to a periodic table and table outlining the common metric prefixes. Both of these resources appear in pop-up browser windows so that they can be viewed concurrently with the tutorial or homework pages.

Checking Homework Status

Based on comments from students who used ReMATCH in the fall semester of 2006, a page displaying the student's ReMATCH homework completion status was provided for students in the fall semester of 2007. Students can refer to this page to determine where they left off when last working on their tutorial homework assignments. This homework report informs students about which questions they have previously answered correctly and the number of times they have attempted each problem. Figure 21 displays a screenshot of a user's completion status page.



Example 1: Using Conversion Factors - Length

Now we can start using some of the conversion factors we have created. Let's think of an example where you might need to change from one set of units to another.

> What if you had a room that you knew was 12 feet long and you wanted to carpet it but the carpet was only sold by the linear yard? What would you do?

You would need to know how many yards are in 12 feet.

You probably already know that all we need to do is divide 12 feet by 3 feet per yard to determine that 12 feet is the same as 4 yards.

But what math is involved when you did this explicitly?

You are doing something called **unit conversion**. In chemistry, we always do unit conversion very explicitly (by writing out every step) in order to reduce our chances of making a mistake.

To solve this problem like a chemist, you would first write down what you are given (in this case, that would be the length of the room, 12 feet). Then, you would multiply it by a conversion factor that relates feet and yards to obtain an answer in yards.

$$12 \text{ feet} \times \frac{1 \text{ yard}}{3 \text{ feet}} = 4 \text{ yards}$$

Why did I end up with the units of yards?

I did because the units of feet cancelled each other out (they appear both above and below the divisor line and so they cancel). **Remember when working with units, they are treated just like numbers. Two of the same units on top of each other in a division problem or a ratio are equal to one and, therefore, can be cancelled as follows.**

$$12 \cancel{\text{feet}} \times \frac{1 \text{ yard}}{3 \cancel{\text{feet}}} = 4 \text{ yards}$$

Now that "yards" is the only unit left on the top of the equation, it must be the only unit in our answer.

Let's try a similar example.

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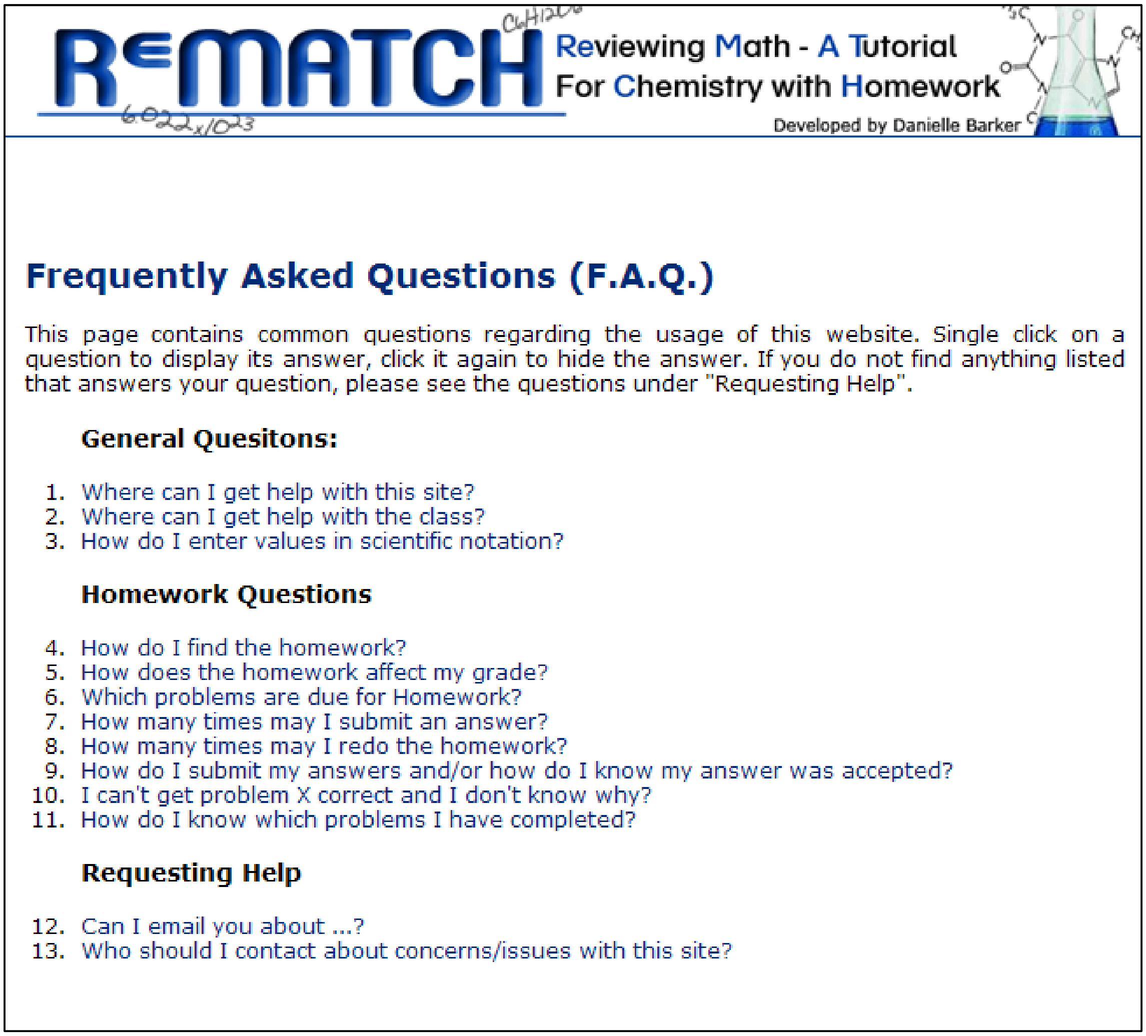
Figure 19 Screenshot of the an everyday context page in ReMATCH provided here to highlight the navigation features on a tutorial page. The Quick Jump button in the upper right corner with its pull down menu options enables users to move between sections. The navigation buttons at the bottom of



ReMATCH
$C_6H_{12}O_6$
6.022×10^{23}
Reviewing Math - A Tutorial For Chemistry with Homework
Developed by Danielle Barker

Frequently Asked Questions (F.A.Q.)

This page contains common questions regarding the usage of this website. Single click on a question to display its answer, click it again to hide the answer. If you do not find anything listed that answers your question, please see the questions under "Requesting Help".

General Quesitons:

1. Where can I get help with this site?
2. Where can I get help with the class?
3. How do I enter values in scientific notation?

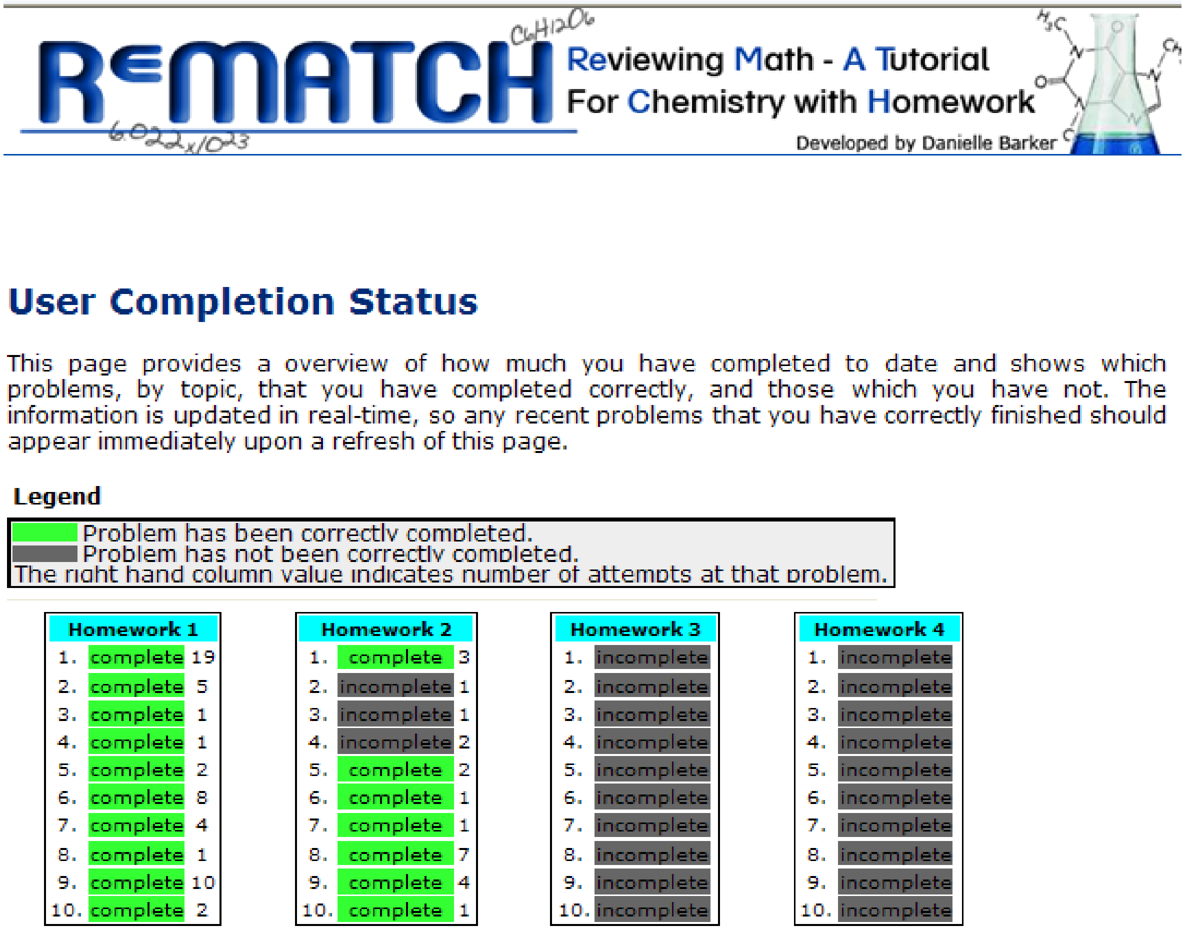
Homework Questions

4. How do I find the homework?
5. How does the homework affect my grade?
6. Which problems are due for Homework?
7. How many times may I submit an answer?
8. How many times may I redo the homework?
9. How do I submit my answers and/or how do I know my answer was accepted?
10. I can't get problem X correct and I don't know why?
11. How do I know which problems I have completed?

Requesting Help

12. Can I email you about ...?
13. Who should I contact about concerns/issues with this site?

Figure 20Screenshot of FAQ page from ReMATCH website.



ReMATCH Reviewing Math - A Tutorial For Chemistry with Homework

Developed by Danielle Barker

User Completion Status

This page provides a overview of how much you have completed to date and shows which problems, by topic, that you have completed correctly, and those which you have not. The information is updated in real-time, so any recent problems that you have correctly finished should appear immediately upon a refresh of this page.

Legend

Problem has been correctly completed.
Problem has not been correctly completed.
The right hand column value indicates number of attempts at that problem.

	Homework 1		Homework 2		Homework 3	Homework 4
1.	complete	19	complete	3	incomplete	incomplete
2.	complete	5	incomplete	1	incomplete	incomplete
3.	complete	1	incomplete	1	incomplete	incomplete
4.	complete	1	incomplete	2	incomplete	incomplete
5.	complete	2	complete	2	incomplete	incomplete
6.	complete	8	complete	1	incomplete	incomplete
7.	complete	4	complete	1	incomplete	incomplete
8.	complete	1	complete	7	incomplete	incomplete
9.	complete	10	complete	4	incomplete	incomplete
10.	complete	2	complete	1	incomplete	incomplete

Figure 21Screenshot of ReMATCH User Completion Status page for referencing which ReMATCH homework problems have been completed and attempted.

the page in the middle of the screen allow users to move between pages within their current section of the tutorial.

The Assignment Cross-Reference is a homework related resource provided to ReMATCH users in the navigation side panel. This link takes students to a page where they can determine the ReMATCH section most applicable to a particular homework problem. Then, they can quickly view worked-examples and metacognitive strategies to assist them in working the homework problem. Figure 22 provides a screenshot of the Assignment Cross Reference page.

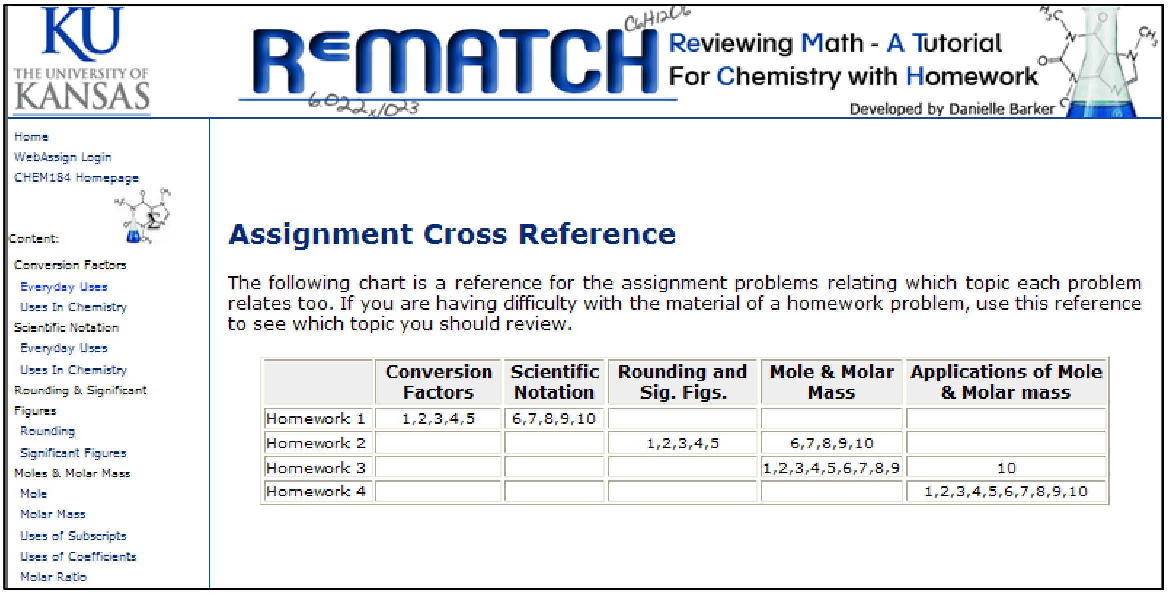


Figure 22 Screenshot of Assignment Cross Reference page for ReMATCH users to determine which topics are associated with which ReMATCH homework problems.

Source of Homework Problems

The majority of the homework problems provided in the ReMATCH tutorial are ones from the their textbook to provide consistency between the lectures, the WebAssign ® homework problems also from their textbook, and the ReMATCH tutorial problems (Chang, 2003). If used in a course with a different textbook in the future, these problems can easily be swapped for ones from the textbook in use. However, for future research on ReMATCH, the creation of homework problems unique to ReMATCH is desired.

ReMATCH Database

The ReMATCH schema was designed around two use-cases: (1) supporting the recording of a user's site-access frequency (logins) and a user's individual tutorial page-access frequency (pages viewed) and (2) supporting the homework problem solutions response system accompanying the site. This student-oriented schema uses the unique identification number, *kuid,* for each student as the primary identifier within the system. Using this identifier, the schema tracks the number of log-ins (the *logins* attribute) in the *User* table (upper left corner of Figure 23), which updates upon each successful log-in by a student. The *Viewed* table (upper right corner of Figure 23) records the name of the ReMATCH page a student views, storing it as the *page* attribute; and, if it is already present, the *Viewed* table updates the number of times the student has loaded the page, recording this value as the *hits* attribute. Since the page name stored is the name of the corresponding webpage, the database tracks any webpage with the ability to access the database with a valid user log-in session.

Student homework results are stored in four identically structured *Homework* tables (four lower tables in Figure 23) representing each set of homework problems present in ReMATCH. The unique identifier relates the homework results to each student. The *pX* attribute, where *X* is the problem number in a specific homework set, indicates if the problem was solved correctly (0 = false, 1 = true). To limit the potential size of these tables, each problem, *pX*, and the number of attempts, *pXAttempts*, is stored on a single row of the table.

To support the website's dynamic homework solution-based system, all homework problem solutions are stored in the *Solutions* table (lower right side of Figure 23). This table stores the answer to each homework problem (the *answer* attribute) along with an upper and a lower boundary for the acceptable answer, the *hi_answer* and *low_answer* attributes, respectively. These boundaries provide a set level of accuracy forgiveness, typically ±2%, to accommodate very slight variations in the values students used in their calculations. The *Solutions* table also stores the expected *units* of the answer, and the required number of significant figures that should be reported in the answer, *sigfigs*. There is no data access relationship between the *Solutions* table and the other tables in the schema; it is accessed by ReMATCH's browser and server-side scripting logic by providing the homework set number and specific problem number, *homework* and *prob_num*, respectively, to determine if a submitted answer meets the correct solution criteria. The database implementation for ReMATCH is an Oracle ® MySQL database that allows administrators to download the schema and all database records to a text file readable by Microsoft Excel ® as the six tables described in Figure 23.

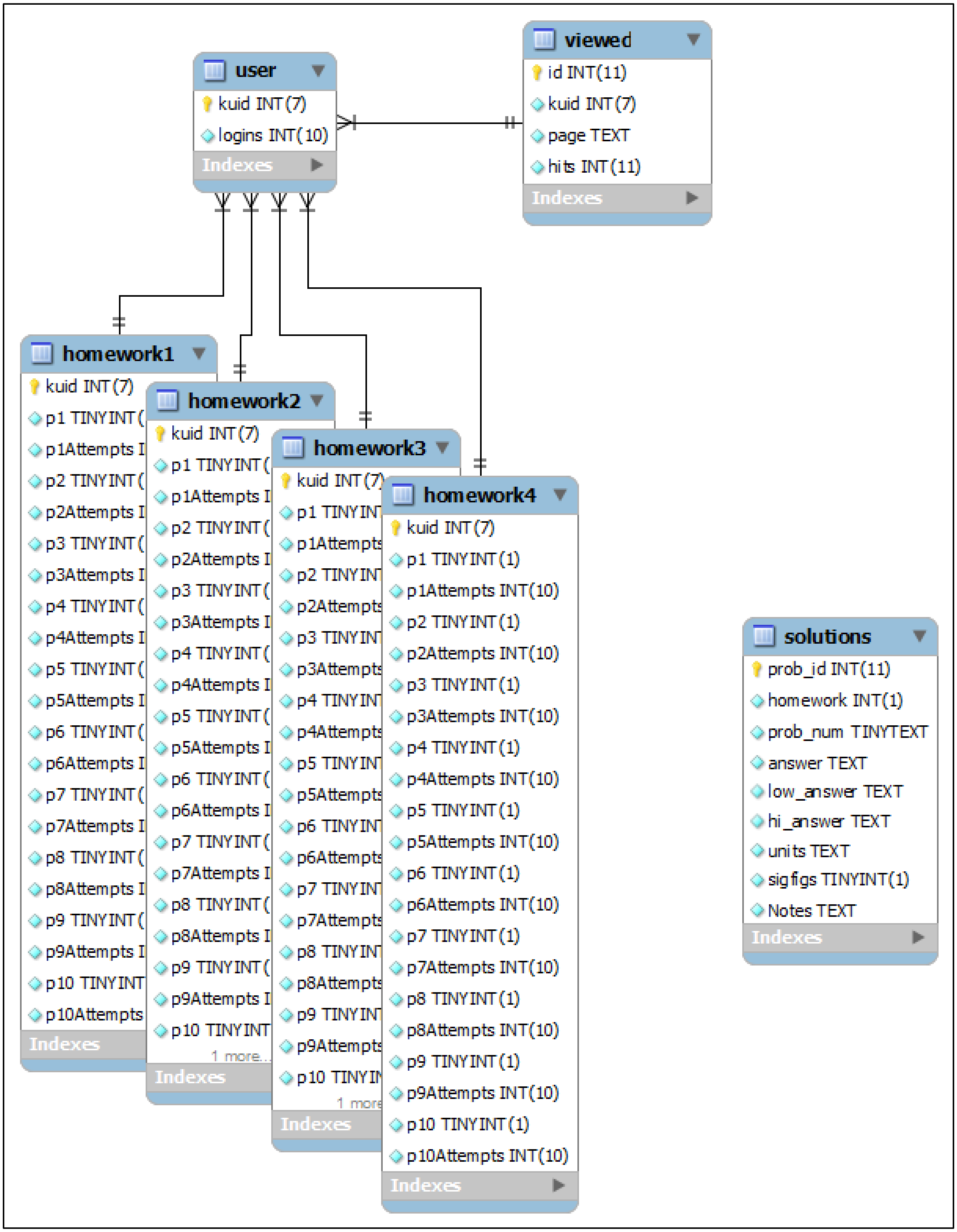


Figure 23 Displays the ReMATCH database architecture schema. This schema illustrates the table structure and relationships between tables in the database.

Chapter 5

Methods

Design

A Quasi-Experimental Approach in 2006

In the fall of 2006, a quasi-experimental research design was chosen to determine whether ReMATCH-use affected student performance in the course and student confidence with several math-related chemistry topics. A nonequivalent groups design with a posttest only experiment was selected to address the question of whether using ReMATCH had an effect on student performance in the course. Covariates were used to control for any nonequivalent demographic or academic background variables that exist between groups. To address whether using ReMATCH affected student confidence with the math-related chemistry topics, a nonequivalent groups design with a pretest-posttest experiment was selected. This design also included covariates when necessary to control for any nonequivalent demographic or academic background variables.

It was not possible to use a quasi-experimental approach to address whether students in the experimental group differed in their attitude towards ReMATCH based on student completion of different amounts of the tutorial assignments. Due to the nature of the question, the comparison group was not present. Research designs without a comparison group are considered non-experimental. Therefore, a non-experimental research design was required, and the question was addressed using post-test only correlational comparisons.

A Non-Experimental, Correlational Approach in 2007

A non-experimental, correlational research design was used in 2007 to address the hypotheses about whether completing different amounts of the ReMATCH tutorial assignments and viewing different numbers of ReMATCH tutorial pages was related to student course performance and student confidence with the math-related chemistry topics. The design was considered *non-experimental* in 2007 because it lacked a comparison group. A nonequivalent groups design with a posttest only comparison was used to address whether completing different amounts of the tutorial assignments affected student course performance and student attitudes towards ReMATCH. This post-test only comparison included covariates when necessary to control for any nonequivalent demographic or academic backgrounds variables. Finally, within the subset of students who all completed the ReMATCH tutorial assignments, a nonequivalent groups design using a pretest-posttest comparison was selected to address the question of whether viewing different numbers of tutorial pages affected student confidence with different math-related chemistry topics. This design also included covariates when necessary.

Procedures

Description of the 2006 Study

Students in the course were assigned to either a comparison or an experimental group in 2006 based on the lab sections in which the students enrolled. Students in the experimental group were assigned portions of the ReMATCH homework assignments to complete for their first four pre-lab assignments, while student in the comparison group completed the traditionally assigned pre-lab assignments over the same period of time. To ensure that the comparison and experimental groups were as similar as possible, one or two of the lab sections offered at each of the nine lab-times were chosen as the experimental lab sections. The lab sections selected during each time-slot depended on which of the instructors leading these sections were amenable to having their students perform the ReMATCH homework assignments in lieu of the first four regular pre-lab assignments. This experimental group consisted of students in 14 lab sections taught by nine instructors. Students in the remaining 33 lab sections did not have any assignments related to ReMATCH but were given the link to the website and allowed to use the tutorial and try the associated homework if they wanted to do so. With this arrangement, the students in both groups were ensured the same lecture experiences. Additionally, while the ReMATCH homework was a required assignment for the experimental group, students in the experimental group who did not complete these ReMATCH assignments did not suffer a large grade penalty.

One-way analysis of variances (ANOVAs) were used with demographic and academic history variables as the dependent variables and participation in the experimental group as the independent variable to confirm that the comparison and experimental student groups did not differ significantly. This confirmation was necessary to validate that meaningful comparisons could be made between the ReMATCH users and the comparison group. Background variables on which the groups differed were considered for use as covariates in further analyses. Comparisons of course performance, survey responses, and ReMATCH-use were conducted between ReMATCH users and the comparison group by using correlations, multiple linear regression analyses, t-tests, and ANOVAs.

Description of the 2007 Study

The demographic and academic history variables of students completing different amounts of the tutorial and viewing different numbers of tutorial pages in the fall of 2007 were compared using ANOVAs to determine whether any significant differences existed between the groups. Any variable on which these groups differed was considered for use as a covariate in further analyses. A variable was included as a covariate in later analyses if the dependent variable for a particular analysis was also significantly correlated with it. Using covariates where necessary, comparisons of course performance, survey responses, and ReMATCH use were made between groups of ReMATCH users completing different amounts of the ReMATCH assignments and between groups of ReMATCH users viewing different numbers of the tutorial pages by using correlations, multiple linear regression analyses, t-tests, and ANOVAs.

Several changes occurred in the study design from 2006 to 2007. The tutorial became required for all general chemistry students in 2007 instead of being required only of students in experimental lab sections. ReMATCH changed from being associated with the laboratory portion of the course in 2006 to the lecture portion in 2007. Additionally, the testing structure for the course was altered between the years; instead of having three lecture exams that were all used in students' grade calculations, four lecture exams were given in 2007 and students were allowed to drop their lowest lecture exam score. Therefore, while one-way ANOVAs were used to compare the background, course performance, tutorial use, and survey response variables of students across the groups of interest from 2006 and 2007, this was only performed to highlight where statistical similarities and differences existed between the different years. The groups from 2006 were not compared to those from 2007 when studying interactions between background variables, course performance, tutorial use, and survey responses because the courses functioned differently.

Data Sources

Student data for the 2006 and 2007 studies obtained from multiple sources focused on a number of topics: (1) demographic and academic backgrounds, (2) attitudes and experiences regarding chemistry and ReMATCH, (3) course performance, and (4) ReMATCH tutorial use. The sources of this data included (1) university records, (2) the course grade book, (3) the initial and final surveys administered via WebAssign®, and (4) the ReMATCH tutorial-user database.

Data from University Records

As during the fall of 2005, data from a number of variables were collected from university records: gender, ethnicity, level in college, matriculation term, status when entering the university, HSGPA, $ACT_{composite}$, ACT_{math}, last college math course completed, grade in last college math course, chemistry lab section, and final grade recorded for the general chemistry course. These variables were defined earlier for the 2005 preliminary research.

Course Grade-Book Records

The course grade-book records obtained from the professor included the following items for each student: letter grade earned, points earned on lecture exams and final exams, homework points earned, lab points earned, and the bonus points obtained. Human subjects' approval was granted for the

2006 and 2007 studies and an informed consent form was used to gain participants in these studies. Because of this approval, and unlike the study in 2005, the university-data gathered in 2006 and 2007 could be linked to students' identifying university numbers and, thereby, to students' course grade-book records. Through the process of linking data from multiple sources, a more informative measure of student performance in general chemistry was available for analysis, the percent of the total exam points students earned. The percent of total exam points earned by students was determined to be a better measure of performance in chemistry because of its truly interval-level nature and its focus on each individual student's chemistry knowledge. The points that students earned for homework and lab contributed to their letter grade, and these were likely to be measures of *academic aptitude* in addition to a student's chemistry knowledge. It was also desirable to avoid using students' cumulative lab scores or homework scores in any comparisons because the lab was where ReMATCH contributed to the grade for the experimental group in 2006 and the homework was where ReMATCH contributed to the grade for all students in 2007.

Data from Survey Responses

In 2006 and 2007, students in general chemistry completed an initial and final survey related to their prior math and science experiences, their perceptions of the course and course material, their actions in this course, and their interaction with the ReMATCH website. Students took the surveys online through the WebAssign® site for the course. While there were slight variations in the initial and final surveys from 2006 to 2007, many of the questions were the same. Combined versions of the initial and the final surveys indicating which questions and answer choices appeared in each year are provided in Appendix B and Appendix C, respectively.

Questions on the initial survey included (1) requests for some demographic and academic history data and (2) questions regarding student attitudes and levels of comfort with math-related chemistry topics. The final survey included (1) requests for updated demographic data, (2) questions regarding current student attitudes and levels of comfort with math-related chemistry topics, (3) questions regarding students' attitudes towards the course and ReMATCH, and (4) questions regarding students' actions and experiences during the course. Some of the attitude and experiences questions in the final survey focused on how ReMATCH users interacted with the ReMATCH homework and tutorial pages. Because several questions differed on the initial and final surveys between the 2006 and 2007 studies, these differences are identified in any survey data presented.

ReMATCH User Database

For students who used the ReMATCH website in 2006 and 2007, the following information was stored in the database associated with the website: number of ReMATCH log-ins, number of ReMATCH problems attempted, total number of attempts for each ReMATCH problems, and number of ReMATCH problems answered correctly. For 2007, ReMATCH users also generated data identifying the specific tutorial pages viewed by each user and the number of times a user viewed a specific page. The ReMATCH-user database was updated during the entire semester such that the values for log-ins, problems attempted, total attempts, pages viewed, and number of views for each page could have been altered by students returning to the ReMATCH tutorial at any point in the semester, even long after the tutorial assignments were due. Completing the ReMATCH assignments was worth 3.0% of the students total course points for the 2006 experimental group and worth 2.5% of the students total course points for the 2007 group.

Participants

All students in the large first-semester general chemistry course for science majors (mainly, pre-pharmacy, biology, chemistry, and some engineering programs) offered during the fall semesters of 2006 and 2007 at the University of Kansas were invited to participate in this study – approximately 900 students per semester. Informed consent was requested of all students in the form of a checkbox on an initial course survey given through the WebAssign® site for course during the first two-weeks of class. Students acknowledged their informed consent to participate in this study by checking the box indicating that they had read the information statement and agreed to participate in the study. An additional request for informed consent was included as a checkbox on the final survey administered through BlackBoard™ during the last two weeks of class in 2007. The professor of the course announced the surveys during lecture to ensure that students were aware of them and encouraged students to complete the surveys by awarding five bonus points for their completing the surveys (out of a total of 1000 course points). Of the 933 students who eventually received a grade of A to F, CR/NC, or W for the course in 2006, 90.0% (n = 840) consented to being included of the study; and, of the 877 who eventually received a grade in 2007, 85.1% (n = 746) consented to being included of the study.

In an attempt to control for the impact of any prior college-level chemistry courses on student performance in this course, any students who had previously taken a chemistry course in college at this institution or elsewhere were removed from the samples. These students were identified in two ways: (1) those who answered "yes" to the initial survey question asking if they had previously taken a chemistry course in college and (2) those students who were not enrolled in a lab section because only students retaking this specific course are not required to be concurrently enrolled in lab. Removing these students reduced the 2006 sample size to 797 (85.5% of the whole class) and the 2007 sample size to 681 (77.7% of the whole class). Finally, any students who did not complete the course for a grade of A to F in either year were removed from the study samples. This brought the final sample size to 784 (84.0% of the class) in 2006 and to 672 in 2007 (76.6% of the class).

In 2006, students in the large general chemistry lecture were divided into one of two groups: comparison (n = 562) and experimental (n = 222). The only difference in the chemistry course experience between students in the experimental and the comparison groups was in the pre-lab assignments: This is where the intervention, ReMATCH, was included for the experimental group. Students in the experimental group were required to complete the 40 ReMATCH homework problems in lieu of their first four pre-lab assignments, resulting in ten ReMATCH problems per week for four weeks. These assignments were due on during the second through fifth weeks of lab.

In 2007, there was no comparison group because all students were considered to be part of the experimental group (n = 672) and required to complete the 40 ReMATCH homework problems as part of the homework component in the lecture-portion of the course. Because the location of the ReMATCH assignments changed and because changes were made to the testing structure of the course, the results from 2007 were not directly comparable to those of the 2006 comparison and experimental groups.

In the sections below, descriptive data on students' demographic and prior academic background variables are provided. In some of the following tables, data from the fall 2005 preliminary study has been provided for comparison purposes and to serve as an indicator that the distribution of students entering this course is relatively stable over time.

Demographic Data

According to the demographic information collected from university records (shown in Table 20), the course consisted of just slightly more males than females and had little ethnic diversity in both 2006 and 2007; over 78% of the enrolled students in 2006 and over 83% in 2007 identified themselves as white when applying to the university. Most of the students enrolled in this course relatively early in their academic path; over 91% of the students in 2006 and over 88% in 2007 were at the freshmen or sophomore level ($\text{Level}_{\text{enrolled}}$). Table 20 also shows that around 89% of the students for both 2006 and 2007 had Freshman listed as their $\text{Status}_{\text{entry}}$. According to the students' years since matriculation, $\Delta Time_{entry}$, the majority of students, around 67% in both years, were in their first year at the university. Table 19 shows that 61% of the students in both years were taking this course in the fall semester of their freshman year, while approximately 5% in 2006 and over 4% in 2007 were enrolled in this course as first semester transfer students. Similar trends for each of these variables were also seen when the comparison and experimental groups in 2006 were separated.

Table 19

Year	Consent Granted		Prior Chemistry Course in College		Grade Recorded with University Records: A to F	Credit/ No Credit	Withdrew
					Students Selected		
2006	Yes	840	No	797	784	13	0
			Yes	43			
	No	93					
2007	Yes	746	No	681	672	4	5
			Yes	65			
	No	131					

Table 20

Summary Statistics for Demographic and Academic-Level Background Variables Comparing Groups of Interest						
Demographic and Academic-Level Background Variables		Percent of Students in Each Group of Interest				
Variable	Variable Categories	2005 All Students (N = 790)	2006 All Students (N = 784)	2006 Comp. Group (N = 562)	2006 Exp. Group (N = 222)	2007 Group (N = 672)
Gender	Female	48.1	49.6	49.8	49.1	46.6
	Male	51.9	50.4	50.2	50.9	53.4
Ethnicity	African American	3.3	4.5	4.4	4.5	1.5
	American Indian	1.4	1.9	2.0	1.8	0.7
	Asian	5.2	8.3	8.7	7.2	6.1
	Caucasian	81.9	78.4	77.2	81.5	83.5
	Hispanic	3.5	3.7	3.9	3.2	2.8
	Non-Resident Alien	2.3	1.3	1.6	0.5	2.5
	Unknown	2.4	1.9	2.1	1.4	2.8
$\text{Level}_{\text{enrolled}}$	Freshman	57.8	66.2	67.6	62.6	67.3
	Sophomore	24.7	25.5	24.7	27.5	21.3
	Junior	13.0	6.8	6.8	6.8	8.9
	Senior	4.4	1.5	0.9	3.2	2.4
$\text{Status}_{\text{entry}}$	Freshman	85.4	88.8	89.7	86.5	89.0
	Transfer	11.6	9.2	8.4	11.3	6.5
	Other	2.9	2.0	2.0	2.3	4.5
$\Delta\text{Years}_{\text{entry}}$	0	60.6	66.7	68.5	65.8	67.8
	1	24.6	23.3	23.2	23.5	22.3
	2	8.6	6.3	6.0	6.8	7.4
	3 or more	6.2	2.8	2.4	4.1	2.5

Table 21

Status When Enrolled in General Chemistry
Comparing Groups of Interest for Each Year

	Percent of Students in Each Group of Interest				
$Status_{enrolled}$	2005 All Students (N = 790)	2006 All Students (N = 784)	2006 Comp. Group (N = 562)	2006 Exp. Group (N = 222)	2007 Group (N = 672)
First Semester Freshmen	50.3	61.0	62.6	56.8	61.2
First Semester Transfers	8.9	5.2	4.3	7.7	4.0
Prior Freshman	7.6	7.7	7.8	7.2	6.8
Prior Sophomore	19.4	18.9	18.3	20.3	17.3
Prior Junior	10.1	5.9	6.0	5.4	8.5
Prior Senior	3.7	1.4	1.0	2.7	2.2

Academic Background Data from University Records for 2006 and 2007 Students

Over 93% of the students in 2006 and 2007 reported HSGPAs to the university, and these $HSGPA_{reported}$ values came from several different grading scales. There were 13 grading scales overall; nine in 2006 and ten in 2007. Three scales seen in 2006 and 2007 were not present in the 2005 preliminary study. These included (1) 6-point weighted, (2) 11-point unweighted, and (3) 120-point weighted scales. In 2006, 55% of enrolled students had $HSGPA_{reported}$ values provided on a 4-point unweighted scale, 37% on a 4-point weighted scale, and 4% on all the other scales combined. In 2007, 46% of enrolled students had $HSGPA_{reported}$ values provided on a 4-point unweighted scale, 41% on a 4-point weighted scale, and 6% on all the other scales combined.

As seen in 2005 preliminary study, the office of admissions converted all $HSGPA_{reported}$ to a 4-point unweighted scale, $HSGPA_{converted}$; and, as before, any $HSGPA_{reported}$ values from weighted scales that are greater than the label for the scale (i.e. a score 4.12 on a 4-point weighted scale) was simply truncated to a $HSGPA_{converted}$ value of 4.0. Because of this truncation, the histograms of the $HSGPA_{converted}$ values for 2006 and 2007 showed sharp spikes at 4.0 similar to the one dealt with in the 2005 preliminary data. These $HSGPA_{converted}$ histograms were not well modeled by a normal curve (see Figure 24). The mean $HSGPA_{converted}$ for the different years and groups of interest are shown in Table 22.

The lack of normality of these $HSGPA_{reported}$ histograms was corrected using the same method that was used with the 2005 data: The $HSGPA_{reported}$ values from the 4-point unweighted and 4-point weighted scales were combined with $HSGPA_{converted}$ values from the other scales to create a 4-point weighted scale simply labeled HSGPA. The $HSGPA_{converted}$ values from these less frequent scales could be used reliably because, as was the case in the preliminary study, no students who provided values on these less common scales scored above their scale's label. Figure 25 shows the histograms for the newly created HSGPA variable that resulted from combining these scales. The mean HSGPA values for each year and *group of interest*, shown in Table 22, were only slightly different from those for $HSGPA_{converted}$ but were modeled better by a normal distribution.

Similar to finding in 2005, the number of general chemistry students with UGPAs was relatively low, just over 35% of the enrolled students in 2006 and 2007 had attended the university for at least one semester prior to enrolling in general chemistry and, therefore, had a prior university grade point average, UGPA. These UGPA values ranged from 0.92 to 4.00. Mean UGPA values are shown in Table 22. The histogram in Figure 26 shows the distribution of UGPAs for students in the 2006 comparison, 2006 experimental, and 2007 groups. Each distribution visually fits a normal curve fairly well and has skewness and kurtosis values less than 2, indicating a fairly normal distribution.

Around 92% of the sampled students in 2006 and 2007 submitted ACT_{math} and $ACT_{composite}$ scores to the university. The ACT_{math} scores ranged from 15 to 36. Figure 27 shows histograms of ACT_{math} scores for each year and *group of interest*; these distributions were fit well by a normal curve. The $ACT_{composite}$ scores ranged from 13 to 35. Figure 28 shows histograms of ACT_{comp} scores for the different years and *groups of interest*; these distributions were, also, fit well by a normal curve.

The last college math courses taken by general chemistry students ($Math_{college}$) and their grades in their last math course ($Math_{grade}$) were also examined in these studies. Between 62-64% of the students in the 2006 and 2007 samples had a grade of A to D for a previous college-level math course. Roughly, 31% of the students in each year had most recently completed a college-level course in college algebra, trigonometry, or pre-calculus, approximately 21% had completed calculus I at the college level, and around 10% had completed calculus II or higher at the college-level. The mean $Math_{grade}$ for all each type of math course across all years and *groups of interest* ranged from 2.9 to 3.2; average values for each group are presented in Table 22. For each of the *groups of interest*, Figure 29 shows the distribution of $Math_{grade}$ for each type of math course; none of these distributions of $Math_{grade}$ resembled a normal curve.

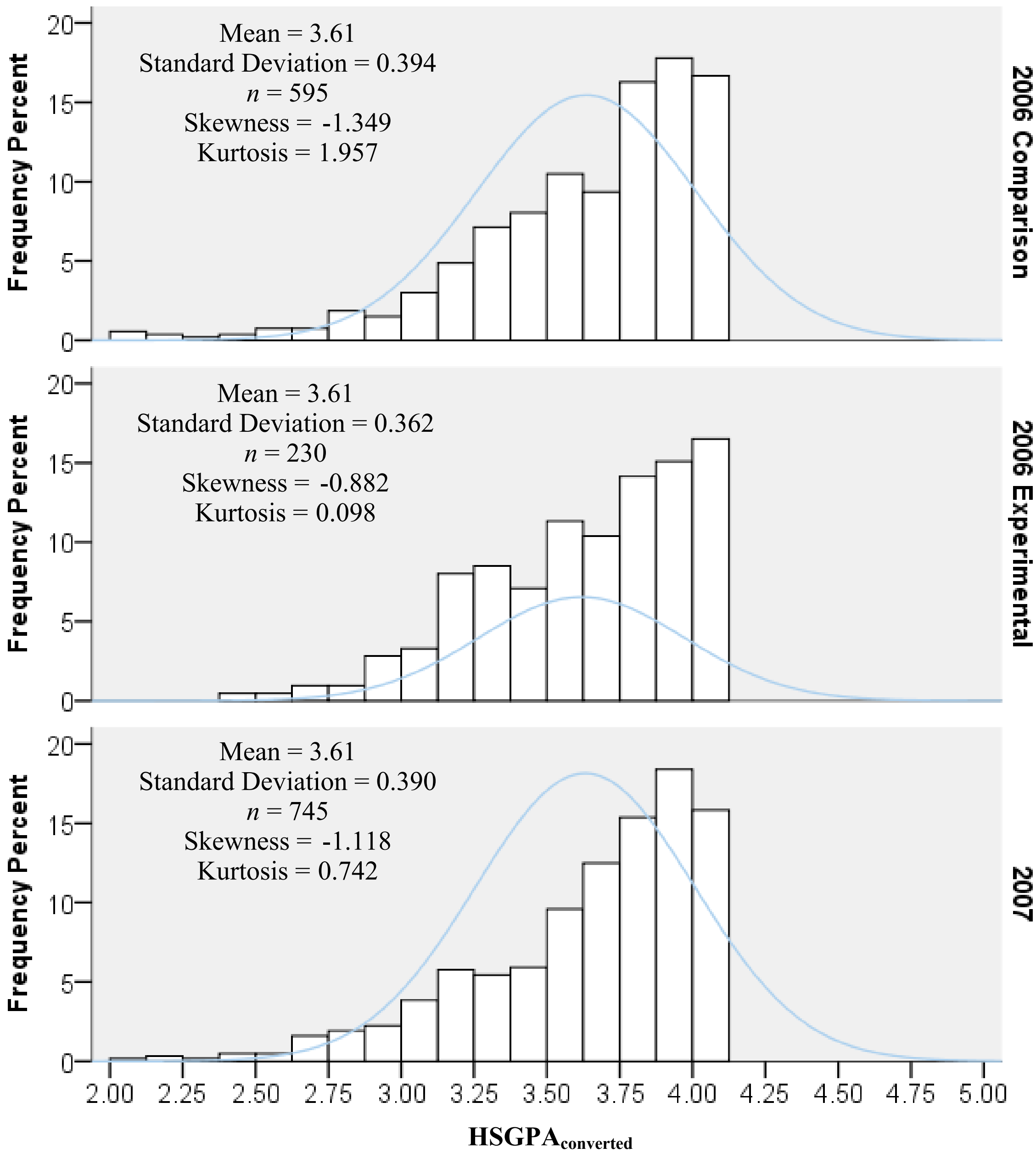


Figure 24 Displays histogram of the distributions of $HSGPA_{converted}$ in the *groups of interest*. These distributions are not well modeled by a normal curve because their values are truncated at 4.0.

Table 22

Summary Statistics of Performance-Related Academic Background and Time Variables Comparing Groups of Interest for Each Year

Performance-Related Academic Background Variable		Mean and Standard Deviation of Each Group of Interest				
Variable		2005 All Students	2006 All Students	2006 Comp. Group	2006 Exp. Group	2007 Group
$HSGPA_{converted}$	*M*	3.62	3.63	3.63	3.63	3.63
	SD	0.405	0.370	0.377	0.354	0.376
	n	713	746	534	212	625
HSGPA	*M*	3.65	3.66	3.66	3.65	3.65
	SD	0.452	0.411	0.415	0.402	0.403
	n	713	746	534	212	625
UGPA	*M*	2.9	2.94	2.91	3.00	3.01
	SD	0.700	0.640	0.640	0.640	0.608
	n	335	276	195	81	241
ACT_{math}	*M*	26.3	25.9	25.9	25.9	26.5
	SD	4.16	3.95	3.88	4.12	4.06
	n	689	730	522	208	617
$ACT_{composite}$	*M*	25.4	25.4	25.4	25.3	25.9
	SD	3.74	3.64	3.63	3.67	3.73
	n	689	730	522	208	617

Mean and Standard Deviation of Grades for Each $Math_{college}$ Category

Variable	Category		2005 All Students	2006 All Students	2006 Comp. Group	2006 Exp. Group	2007 Group
$Math_{grade}$	CollgAlg/Trig/PreCal	*M*	3.2	3.2	3.1	3.2	3.2
		SD	0.84	0.85	0.87	0.81	0.91
		n	215	260	186	74	201
	Calculus I	*M*	2.9	3.1	3.1	2.9	3.1
		SD	0.91	0.92	0.92	0.90	0.91
		n	204	176	129	47	133
	Calculus II or Above	*M*	3.0	3.2	3.2	3.2	3.1
		SD	0.92	0.91	0.94	0.88	0.87
		n	84	67	42	25	80

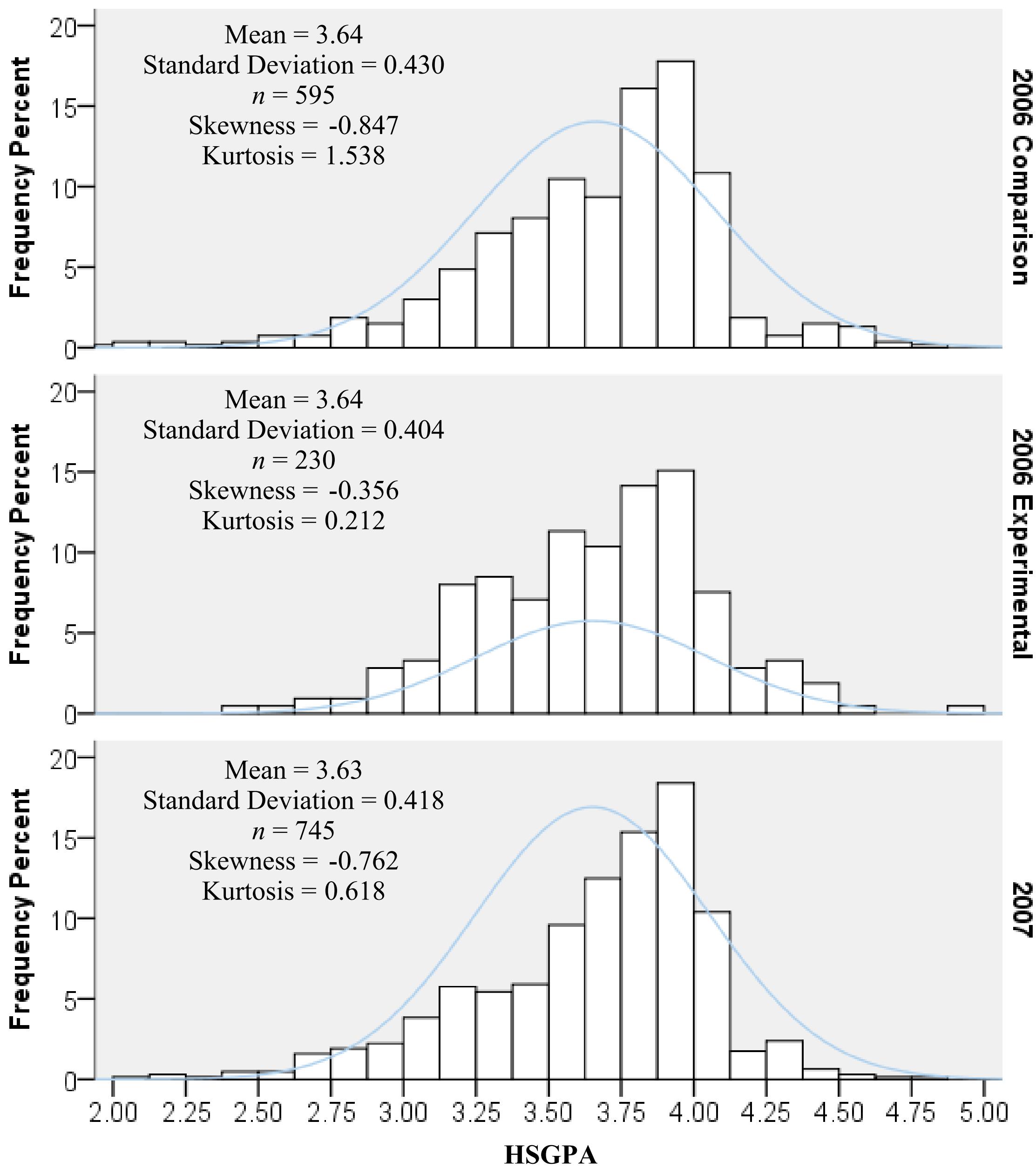


Figure 25 Displays histogram of the distributions of HSGPA in the *groups of interest.* These distributions are much more normal than the ones for $HSGPA_{converted}$.

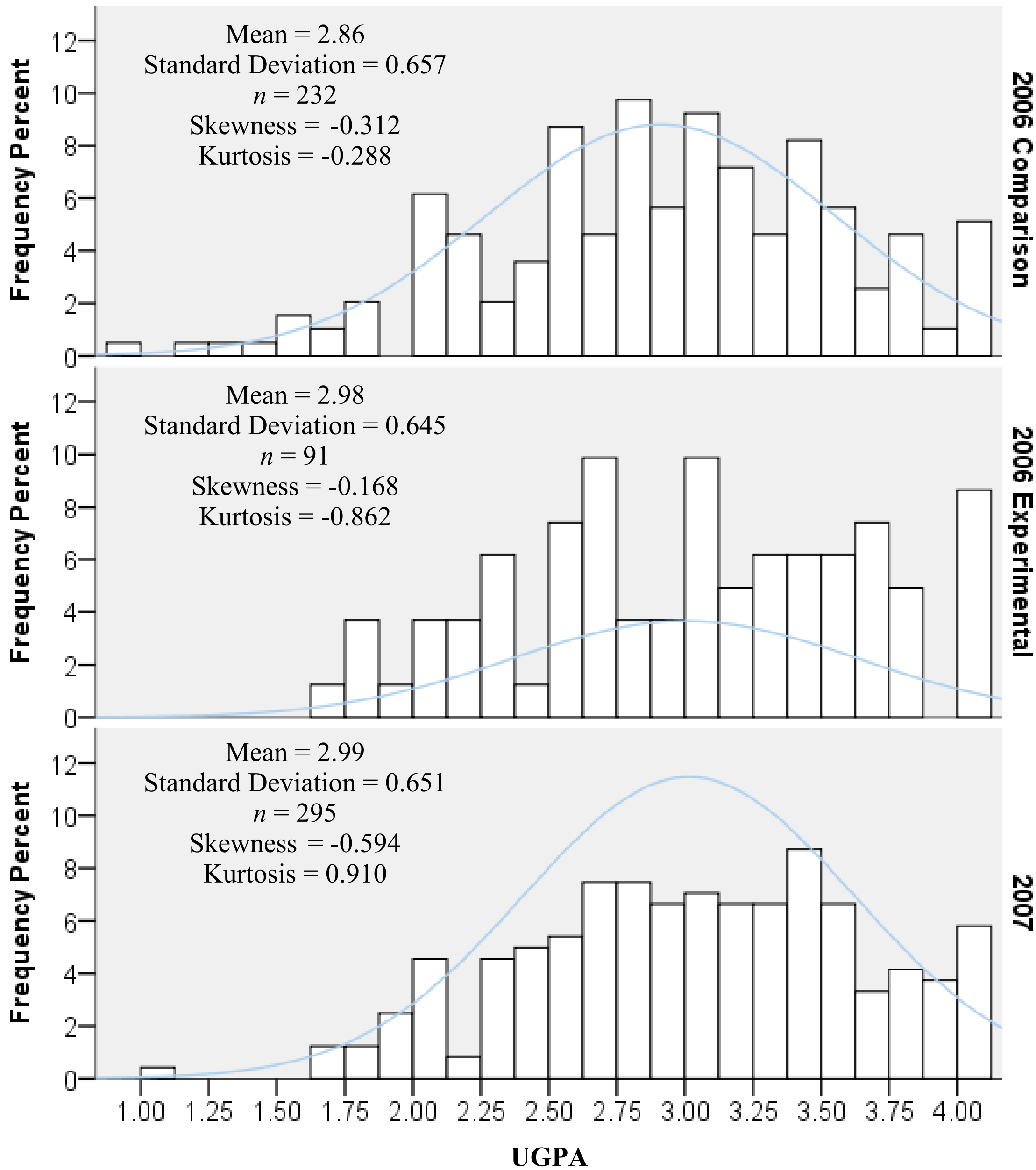


Figure 26Displays histogram of the distributions of UGPA for the *groups of interest.*

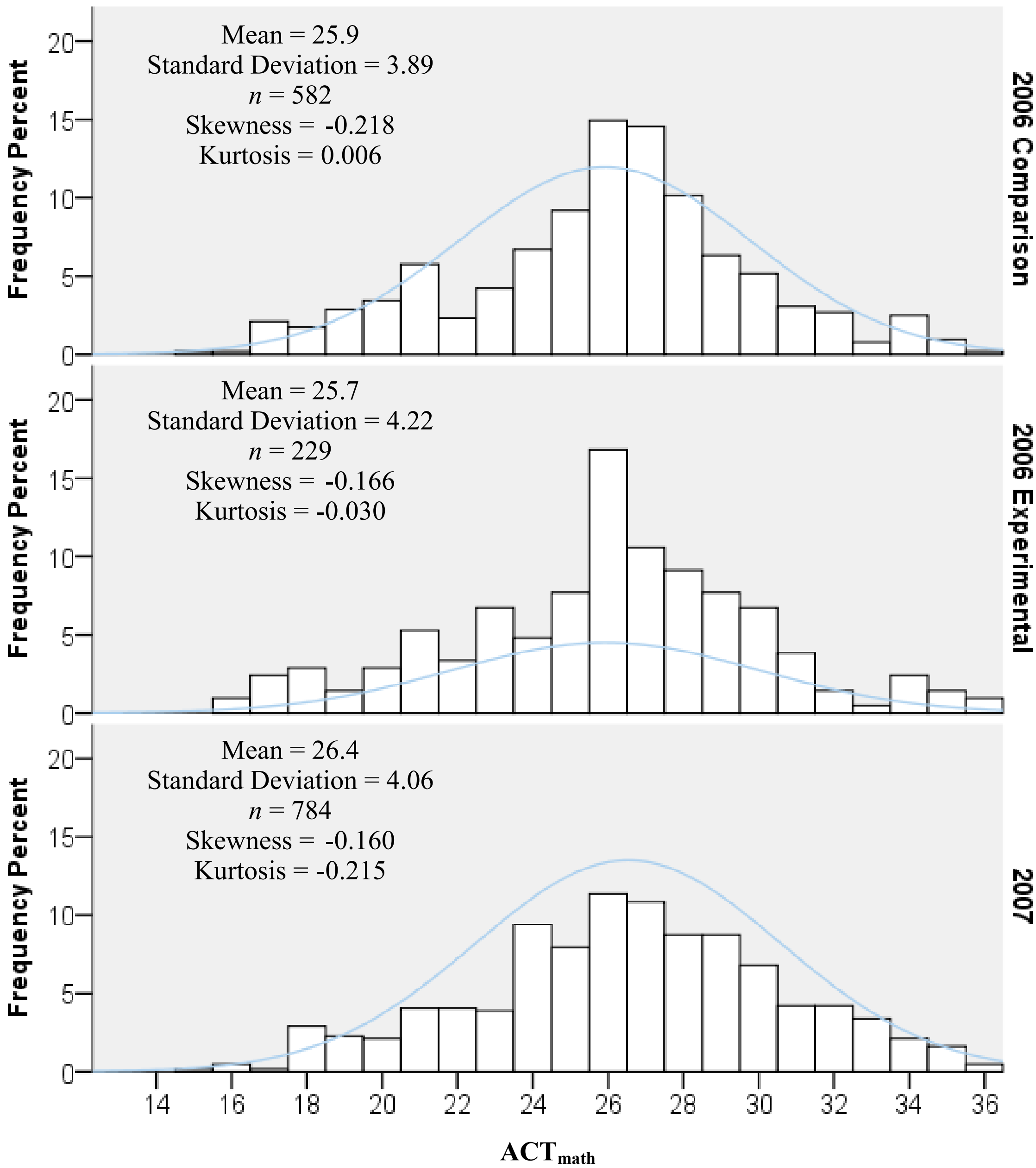


Figure 27 Displays histogram of the distributions of ACT_{math} for the *groups of interest.* These distributions are much more normal than the ones for $HSGPA_{converted}$.

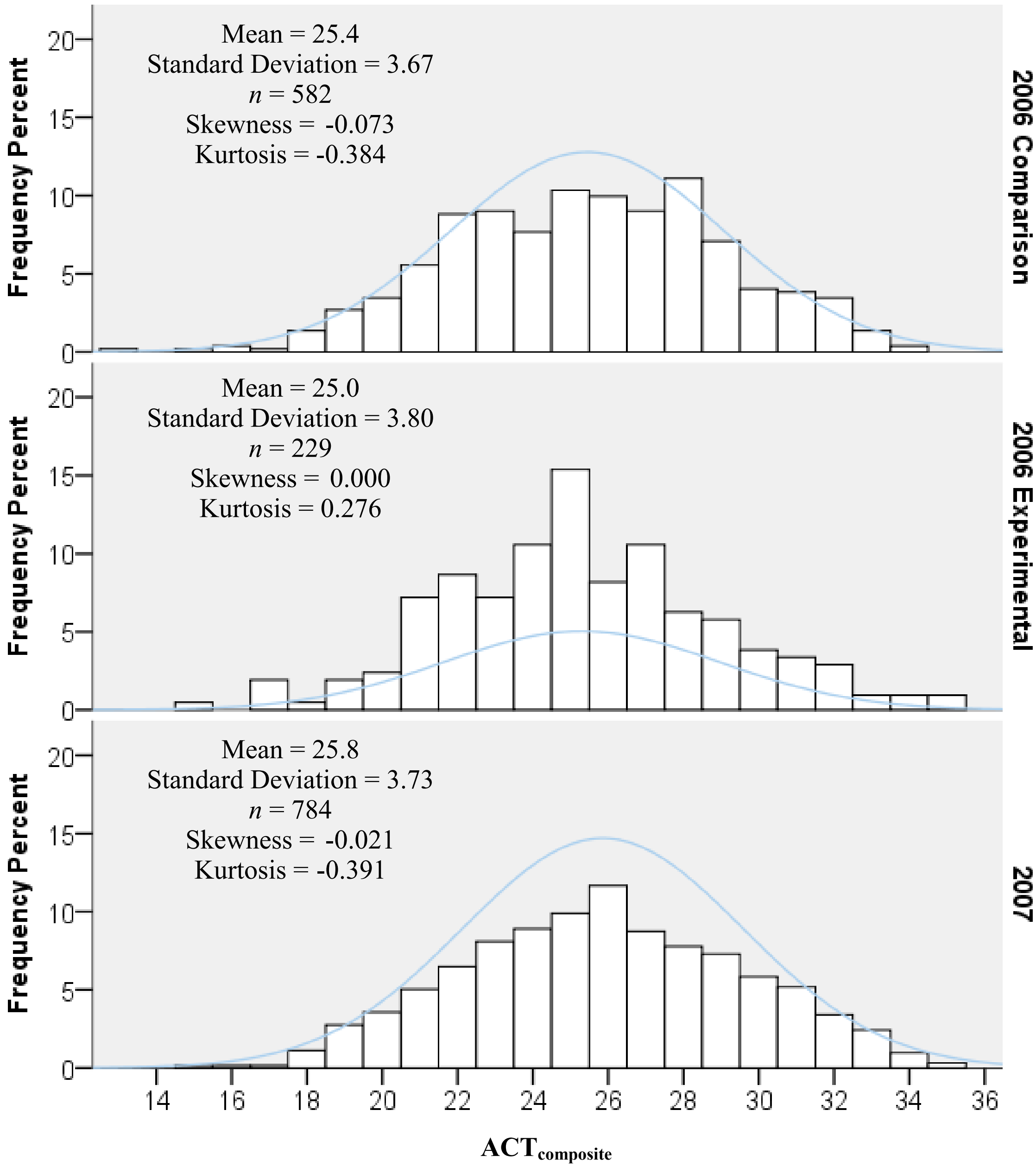


Figure 28 Displays histogram of the distributions of $ACT_{composite}$ in the *groups of interest.*

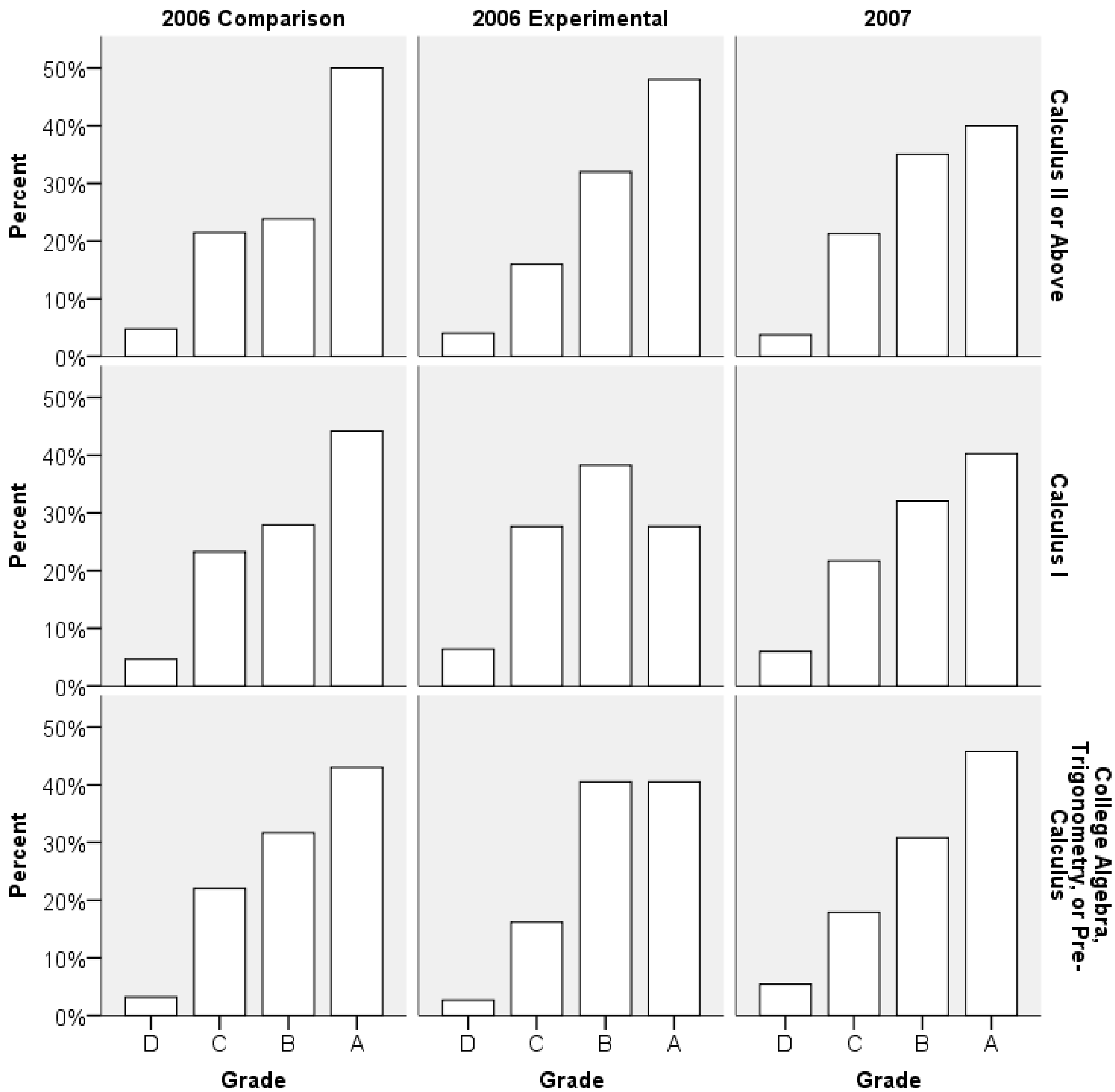


Figure 29. Distribution of math gades by last math coures completed.

Chapter 6

Results of Background, Tutorial Use, and Course Performance Data

Demographic and Academic Background Variables

The summary statistics of the demographic and academic background variables were provided in the *Methods* section for both the 2006 and 2007 studies to describe the participants in fuller detail. Therefore, this chapter begins by presenting the findings from ANOVAs and correlations examining the interrelationships between the demographic and academic background variables collected from university records. Then, summary statistics regarding student use of the ReMATCH website are provided and relationships existing between tutorial-use variables and background variables are explored via correlational analyses. Finally, this chapter summarizes course performance data and investigates relationships within the data collected from the grade book for the course. These comparisons were conducted to identify on which background variables members of the following groups differed significantly:

(1) the 2006 comparison group, the 2006 experimental group, and the 2007 group,

(2) the subsets of tutorial users from the 2006 experimental group, and

(3) the subsets of tutorial users from the 2007 group.

Any variables displaying a significant difference between categories of one of the groups of interest listed above were identified as possible covariates in further analyses.

ANOVAs of Demographic and Academic Level Background Variables

To determine whether any significant differences existed between the students in the three *groups of interest* in the 2006 and 2007 studies (2006 comparison, 2006 experimental, and 2007 groups), demographic and academic background variables were used as dependent variables in separate, one-way ANOVAs including the *groups of interest* as the categorical independent variable for each analysis. The creation of dichotomous variables from each of the unique categories of the following background variables permitted the use of these as dependent variables in the ANOVAs: ethnicity, residency, $\text{Status}_{\text{entry}}$, $\text{Math}_{\text{college}}$, and $\text{Status}_{\text{enrolled}}$. Ethnicity categories constituting 3% or less of the *groups of interest* were combined into a category labeled *other*. Background variables that were interval, such as $\Delta\text{Years}_{\text{entry}}$ and $\text{Level}_{\text{enrolled}}$, or naturally dichotomous, such as gender, did not have to be altered prior to being used as dependent variables in the ANOVAs. This resulted in a set of 19 dichotomous and interval-level variables on which the *groups of interest* were compared (Table 23).

For each categorical variable, Table 23 presents the percent of students in each group who were members of the identified categories of the variable. Under these percentages for each dependent variable, Table 23 presents the ANOVA results obtained by comparing the percentages across the *groups of interest*. As was described in more detail in the analysis of data in the Preliminary Research (Chapter Three), Levene's tests for each dichotomous or interval-level variable were conducted to determine whether a variable's distribution of variance across the *groups of interest* was homogeneous. When a Levene's test was significant (homogeneity of variance was lacking), the statistical significance of the ANOVA was based on the Welch-*F* statistic instead of the traditional *F*-statistic. The ANOVA results in Table 23 clearly mark the variables on which the *groups of interest* differed significantly ($p < .05$) and the variables lacking homogeneity of variance, which, therefore, use the Welch-*F* statistic to determine their significance.

Each non-significant result shown in Table 23 revealed that the percentage of category membership within each of the *groups of interest* did not differ significantly. Of the 19 demographic and academic-level variables, the *groups of interest* only differed significantly on the four following variables:

Ethnicity = African American,

Ethnicity = Caucasian,

$\text{Status}_{\text{entry}}$ = Other, and

$\text{Math}_{\text{college}}$ = Calculus II & Above.

For each of these significant ANOVAs, the η^2 indicated that the strength of the relationship between the dependent variable and the *groups of interest* was weak, with the *groups of interest* accounting for less than 1% of the variance present for each of the dependent variables ($\eta^2 < .01$) (Table 23). Eta squared, η^2, is a measure of effect size used with ANOVAs. Similar to the R^2 value obtained in multiple linear regression analyses, the η^2 value is a measure of association between the independent and dependent variables of ANOVAs and are typically interpreted as follows: .01, small (independent variable accounts for 1-5% of the variance in the dependent variable); .06, medium (independent variable accounts for 6-13% of the variance in the dependent variable); and .14, large (independent variable accounts for 14% or more of the variance in the dependent variable), (Ellis, 2010). When follow-up pairwise comparisons of the group means were conducted, the Dunnett C correction was selected because these variables displayed unequal variance across the *groups of interest*. For each of these four background variables, statistically significant differences existed solely between the 2006 comparison group and the 2007 group (two groups that will not be compared in any future analyses). Compared to the 2007 group, the 2006 comparison group consisted of significantly more African American students, fewer Caucasian students, fewer students who entered the university with $\text{Status}_{\text{entry}}$ = Other, and fewer students whose last college-level math course was Calculus II or higher. None of the demographic or academic-level background comparisons showed any statistically significant differences between students from the 2006 comparison group and the 2006 experimental group. Because few significant differences existed and those that were present only existed between groups that would not be directly compared in further analyses, the *groups of interest* were not considered significantly different regarding the demographic and academic-level background variables.

ANOVAs of Performance- and Time-Related Academic Background Variables

As with the dichotomous demographic and level-related background variables, ANOVAs of the interval-level performance- and time-related academic background variables were also conducted. Table 24 displays the means, standard deviations, and ANOVA results for these comparisons. All of these interval-level variables – HSGPA, UGPA, ACT_{math}, $\text{ACT}_{\text{composite}}$, $\text{Math}_{\text{grade}}$, and $\Delta\text{Years}_{\text{entry}}$ –

exhibited homogeneity of variance across the *groups of interest* as evidenced by their non-significant Levene's tests. Results from separate one-way ANOVAs with each of these six variables as the dependent variable established that the *groups of interest* differed significantly only in their mean ACT_{math} scores. The strength of the relationship between ACT_{math} score and *groups of interest* was weak, as assessed by η^2. The *groups of interest* accounted for less than 1% of the variance present in ACT_{math} ($\eta^2 < .01$) (Table 24). Post-hoc comparisons using the Bonferroni correction (Field, 2009) showed that the sole statistically significant difference in mean ACT_{math} scores existed between the 2006 comparison group and the 2007 group. No statistically significant differences existed between the 2006 comparison and the 2006 experimental groups or between the 2006 experimental and 2007 groups. The students in this study had similar mean HSGPAs, UGPAs, $ACT_{composite}$ scores, $Math_{grade}$, and $\Delta Years_{entry}$ values across the *groups of interest*. Therefore, in addition to their similar demographic and academic-level background variables, the *groups of interest* were also not considered to differ significantly on the performance- and time-related academic background variables.

Table 23

Summary Statistics and ANOVA Results for Demographic and Academic-Level Background Variables Comparing Groups of Interest from 2006 and 2007				
Demographic and Academic-Level Background Variables		Percent of Students in Each Group of Interest		
Variable	Variable Categories	2006 Comp. Group ($N = 562$)	2006 Exp. Group ($N = 222$)	2007 Group ($N = 672$)
Gender	Female	49.8	49.1	46.6
	Male	50.2	50.9	53.4
ANOVA Results[a]	Gender	F (2, 1453) = 0.69,	p = .50,	η^2 = .001
Ethnicity	African American	4.4	4.5	1.5
	Asian	8.7	7.2	6.1
	Caucasian	77.2	81.5	83.5
	Hispanic	3.9	3.2	2.8
	Other	5.7	3.7	6.0
ANOVA Results[a]	**African American[b]**	**F (2, 525.5) = 5.79,**	**p = .003,**	**η^2 = .007**
	Asian[b]	F (2, 602.7) = 1.51,	p = .22,	η^2 = .002
	Caucasian[b]	**F (2, 608.5) = 3.79,**	**p = .023,**	**η^2 = .005**
	Hispanic	F (2, 1453) = 0.58,	p = .56,	η^2 = .001
	Other[b]	F (2, 672.6) = 1.36,	p = .26,	η^2 = .001
$Level_{enrolled}$	Freshman	67.6	62.6	67.3
	Sophomore	24.7	27.5	21.3
	Junior	6.8	6.8	8.9
	Senior	0.9	3.2	2.4
ANOVA Results[a]	$Level_{enrolled}$[b] (interval)	F (2, 601.6) = 1.80,	p = .17,	η^2 = .061
$Status_{entry}$	Freshman	89.7	86.5	89.0
	Transfer	8.4	11.3	6.5
	Other	2.0	2.3	4.5
ANOVA Results[a]	Freshman[b]	F (2, 594.1) = 0.74,	p = .48,	η^2 = .001
	Transfer[b]	F (2, 572.2) = 2.29,	p = .10	η^2 = .004
	Other[b]	**F (2, 639.7) = 3.69**	**p = .026,**	**η^2 = .005**
$Math_{college}$	No College Math	36.8	31.8	37.8
	CollegeAlg/Trig/PreCal	33.0	34.6	29.9
	Calculus I	22.8	21.5	20.1
	Calculus II & Above	7.4	12.2	12.2
ANOVA Results[a]	No College Math[b]	F (2, 618.4) = 0.89,	p = .41,	η^2 = .001
	CollegeAlg/Trig/PreCal[b]	F (2, 606.3) = 1.07,	p = .34,	η^2 = .001
	Calculus I	F (2, 1453) = 0.75,	p = .47.	η^2 = .001
	Calculus II & Above[b]	**F (2, 597.3) = 4.39,**	**p = .013,**	**η^2 = .005**
$Status_{enrolled}$	First Sem. Freshman	62.8	56.8	61.2
	First Sem. Transfer	4.4	7.7	4.0
	Prior Freshman	7.7	7.2	6.8
	Prior Sophomore	18.3	20.3	17.3
	Prior Junior or Senior	6.8	8.0	10.6
ANOVA Results[a]	First Sem. Freshman[b]	F (2, 608.3) = 1.13,	p = .32,	η^2 = .002
	First Sem. Transfer[b]	F (2, 562.9) = 1.79,	p = .17,	η^2 = .004
	Prior Freshman	F (2, 1453) = 0.16,	p = .85,	η^2 < .001
	Prior Sophomore	F (2, 1453) = 0.52,	p = .59,	η^2 = .001
	Prior Junior or Senior[b]	F (2, 620.8) = 2.59,	p = .076,	η^2 = .004

a. ANOVA results shown in **bold** are significant at the α = .05 level.
b. The Welch F-statistic was used to determine significance due to heterogeneity of variance.

Table 24

Summary Statistics and ANOVA Results for Performance- and Time-Related Academic Background Variables Comparing Groups of Interest from 2006 and 2007

Performance- and Time-Related Academic Background Variable			Mean and Standard Deviation for Each Group of Interest		
Variable			2006 Comparison Group	2006 Experimental Group	2007 Group
HSGPA		*M*	3.66	3.65	3.65
		SD	0.415	0.402	.403
		n	534	212	625
ANOVA Results[a]	HSGPA		*F* (2, 1368) = 0.11,	*p* = .90,	$\eta^2 < .001$
UGPA		*M*	2.91	3.00	3.01
		SD	0.640	0.640	0.608
		n	195	81	241
ANOVA Results[a]	UGPA		*F* (2, 514) = 1.56,	*p* = .21,	$\eta^2 = .006$
ACT_{math}		*M*	25.9	25.9	26.5
		SD	3.88	4.12,	4.06
		n	522	208	617
ANOVA Results[a]	**ACT_{math}**		***F* (2, 1344) = 4.02,**	***p* = .018,**	**$\eta^2 = .006$**
$ACT_{composite}$		*M*	25.4	25.3	25.9
		SD	3.63	3.67	3.73
		n	522	208	617
ANOVA Results[a]	$ACT_{composite}$		*F* (2, 1344) = .2.66,	*p* = .07,	$\eta^2 = .004$
$Math_{grade}$		*M*	3.1	3.2	3.2
		SD	0.90	0.87	0.90
		n	186	74	201
ANOVA Results[a]	$Math_{grade}$		*F* (2, 927) = 0.34,	*p* = .72,	$\eta^2 = .001$
$\Delta Years_{entry}$		*M*	0.44	0.50	0.48
		SD	0.792	0.828	0.870
		n	562	222	672
ANOVA Results[a]	$\Delta Years_{entry}$		*F* (2, 1453) = 0.57,	*p* = .56,	$\eta^2 = .001$

a. ANOVA results shown in **bold** are significant at the $\alpha = .05$ level.

Correlations Between Background Variables

Results from correlations in 2006.

Bivariate correlations between several demographic background variables and the performance-related academic background variables were conducted to explore whether students of different genders, ethnicities, or levels in college entered general chemistry in 2006 with similar levels of prior performance (Table 25). All but three of these demographic variables, Ethnicity = Asian, $\text{Level}_{\text{enrolled}}$ = Senior, and $\text{Math}_{\text{college}}$ = Calculus I, shared significant correlations of weak to moderate strength with one or more of the performance-related background variables. Of the 23 background variables listed, 18 correlated significantly with ACT_{math}, 17 with $\text{ACT}_{\text{composite}}$, 14 with HSGPA, 9 with UGPA, and 9 with $\text{Math}_{\text{grade}}$.

The correlations shown in Table 25 identified several interesting relationships between the demographic and performance-related background variables.

(1) Ethnicity = Caucasian and $\text{Status}_{\text{enrolled}}$ = First Semester Freshman displayed a significant positive correlation with each performance-related academic background variable.

(2) Ethnicity = African American, Hispanic, and Other displayed a significant negative correlation with two or more of the performance-related background variables.

(3) Gender = Female displayed a significant correlation for each of the performance-related academic background variables; however, the direction of the relationships varied.

   a. Female students displayed significant positive correlations with each grade-related background variable, HSGPA, UGPA, and $\text{Math}_{\text{grade}}$, and

   b. Female students displayed significant negative correlations with both standardized-test-related background variable, ACT_{math} and $\text{ACT}_{\text{composite}}$.

Significant bivariate correlations were identified between the levels of $\text{Math}_{\text{college}}$ and the performance-related academic background variables; these also showed some interesting relationships.

(1) $\text{Math}_{\text{college}}$ = Calculus II displayed a significant positive correlation with each performance-related background variable, except $\text{Math}_{\text{grade}}$.

(2) $Math_{college}$ = College Algebra, Trigonometry, or Pre-Calculus displayed a significant negative correlation with each performance-related variable, except $Math_{grade}$.

Additionally, these correlations showed some interesting relationships between the level- and time-related variables and the performance-related background variables.

(1) $Status_{enrolled}$ = First Semester Freshman displayed a significant positive correlation with each performance-related background variable.

(2) $Level_{enrolled}$ = Sophomore, Junior, or Senior, $Status_{enrolled}$ = Prior Freshman, Prior Sophomore, or Prior Junior or Senior, and $\Delta Years_{entry}$ – demographic variables indicating that a student had attended KU for a year or more – displayed significant negative correlations with one or more of the performance-related background variables.

(3) $Status_{entry}$ values of Transfer and Other displayed a significant negative correlation with three of the performance-related background variables.

In summary, a bivariate correlational analysis of the 2006 data suggested that Caucasian students entering the university directly from high school (those with $Status_{entry}$ = Freshman and $\Delta Years_{entry}$ = 0) had higher values on measures of previous academic performance. On average, females in the course reported higher values for previous grade-related measures, and males reported higher previous standardized-test scores (Greenfield, 1996; Hamilton, 1998; Walding, Fogliani, Over, & Bain, 1994). When looking at students with prior college-level math coursework, those who completed calculus II or above prior to enrolling in general chemistry typically had higher values on previous performance measures. Those whose last college-level math course was college algebra, trigonometry, or pre-calculus typically had lower values on previous academic-performance measures.

Results from correlations in 2007.

To determine if the same trends found in the demographic and academic background variables for the 2006 data were also present in the 2007 data, bivariate correlations were conducted between the demographic background variables and the performance-related academic background variables from the 2007 data. These correlations for 2007 are shown in Table 26. For the 2007 study, six of these demographic variables, Ethnicity = Asian, Hispanic, and Other, $Level_{enrolled}$ = Senior, $Status_{entry}$ = Other, and $Math_{college}$ = Calculus I, did not share significant correlations with the performance-related background variables. The other 17 demographic variables shared significant correlations of weak to moderate strength with one or more of the performance-related background variables. Of the 23 demographic variables listed, 11 correlated significantly with ACT_{math}, 13 with $ACT_{composite}$, 14 with HSGPA, 4 with UGPA, and 12 with $Math_{grade}$.

For the most part, the relationships identified in 2006 were also identified as significant in 2007; however, some differences did exist between the years. The correlations shown in Table 26 identify some interesting relationships between the demographic and the performance-related background variables present in 2007.

(1) Ethnicity = Caucasian displayed a significant positive correlation with $ACT_{composite}$.

(2) Ethnicity = African American displayed a significant negative correlation with each performance-related background variables.

(3) Gender = Female displayed a significant correlation with each performance-related academic background variables, except $ACT_{composite}$; however, the direction of the relationships varied as it did in the 2006 analysis.

   a. Female students displayed significant positive correlations with each grade-related background variable, HSGPA, UGPA, and $Math_{grade}$, and

   b. Female students displayed significant negative correlations with one of the standardized-test-related background variable, ACT_{math}.

In 2007, significant correlations also existed between students' last college-level math course and their performance-related academic background variables.

(1) $Math_{college}$ = Calculus II displayed a significant positive correlation with each performance-related variable, except UGPA and $Math_{grade}$.

(2) $Math_{college}$ = College Algebra, Trigonometry, or Pre-Calculus displayed a significant negative correlation with each performance-related variable, except UGPA and $Math_{grade}$.

Finally, when correlations were examined between level- and time-related background variables and performance-related background variables, significant correlations were also present for the 2007 data.

(1) $Status_{enrolled}$ = First Semester Freshman displayed a significant positive correlation with each performance-related academic background variable.

(2) $Level_{enrolled}$ = Sophomore or Junior, $Status_{enrolled}$ = Prior Freshman, Prior Sophomore, or Prior Junior or Senior, and $\Delta Years_{matriculation}$ – demographic variables indicating that a student had attended KU for a year or more – displayed significant negative correlations with one or more of the performance-related background variables.

(3) $Status_{entry}$ = Transfer displayed a significant negative correlation with each performance-related background variables.

In summary, the same general trends were seen in 2007 as were originally shown in 2006 study but the correlations were weaker in 2007. Typically, Caucasian students entering the university directly from high school (those with $Status_{entry}$ = Freshman and $\Delta Years_{entry} = 0$) came with higher values on measures of previous academic performance. On average, females in the course reported higher values for previous grade-related measures, and males reported higher previous standardized-test scores, though only significantly so for ACT_{math} in 2007. As in 2006, when looking at students with prior college-level math coursework, those who completed calculus II or above prior to enrolling in general chemistry typically had higher values on previous performance measures, while those whose last college-level math course was college algebra, trigonometry, or pre-calculus typically had lower values on previous performance measures.

ANOVAs of Select Performance-Related Background Variables with $Status_{enrolled}$

To demonstrate the degree of the previous performance differences for different levels of students enrolled in general chemistry, Figure 30 and Figure 31 show boxplots of the mean HSGPA and ACT_{math} values, respectively, across the different levels of the $Status_{enrolled}$ variable for both 2006 and 2007. These plots clearly show that the mean HSGPA and ACT_{math} scores of students with $Status_{enrolled}$ = First Semester Freshman are higher than the scores of students in several other categories of $Status_{enrolled}$. Separate one-way ANOVAs were conducted to confirm which of these differences were significant. In 2006, ANOVAs using the Welch-*F* statistic showed that both HSGPA, F (5, 59.8) =

26.3, $p < .001$, $\eta^2 = .17$, and ACT_{math}, $F(5, 51.2) = 13.8$, $p < .001$, $\eta^2 = .098$, differed significantly based on $Status_{enrolled}$. The effect-size for each of these results in 2006, as assessed by η^2, was of moderate strength, with nearly 10% of the variance in ACT_{math} and 17% of the variance in HSGPA accounted for by $Status_{enrolled}$. Post-hoc pairwise comparisons using the Dunnett C correction were performed to determine the specific $Status_{enrolled}$ categories with significantly different HSGPA and ACT_{math} means.

For HSGPA,

(1) First Semester Freshmen differed significantly from Prior Freshman and Prior Sophomore.

(2) Prior Freshman differed significantly from Prior Sophomore and Prior Junior.

For ACT_{math},

(1) First Semester Freshmen differed significantly from Prior Freshman, Prior Sophomore, and Prior Junior.

(2) Prior Freshman differed significantly from First Semester Transfer.

The ANOVAs on the 2007 data, using a traditional *F* statistic for HSGPA and the Welch-*F* statistic for ACT_{math}, showed that again HSGPA, $F(5, 619) = 16.9$, $p < .001$, $\eta^2 = .12$, and ACT_{math}, $F(5, 48.6) = 34.5$, $p < .001$, $\eta^2 = .17$, differed significantly due to $Status_{enrolled}$. The effect-size for both results in 2007, as assessed by η^2, was of moderate strength, with 17% of the variance in ACT_{math} and 12% of the variance in HSGPA accounted for by $Status_{enrolled}$. Post-hoc pairwise comparisons, using the Bonferroni correction for HSGPA and the Dunnett C correction for ACT_{math}, were performed to determine the specific groups $Status_{enrolled}$ categories with significantly different HSGPA and ACT_{math} means.

For HSGPA,

(1) First Semester Freshmen differed significantly from Prior Freshman and Prior Sophomore.

(2) Prior Freshman differed significantly from Prior Sophomore, Prior Junior, and Prior Senior.

For ACT_{math},

(1) First Semester Freshmen differed significantly from Prior Freshman, Prior Sophomore, First Semester Transfer, and Prior Senior.

(2) Prior Freshman differed significantly from Prior Sophomore and Prior Junior.

Table 25

2006 Correlations Between Demographic or Academic Background Variables and Prior Academic Performance Variables

		HSGPA (n = 746)	ACT_{math} (n = 730)	$ACT_{composite}$ (n = 730)	UGPA (n = 276)	$Math_{grade}$ (n = 510)
Female	r	.234**	-.224**	-.076*	.185**	.142**
	p	.000	.000	.041	.002	.001
Ethnicity = African American	r	-.087*	-.149**	-.091*	-.115	-.080
	p	.017	.000	.014	.057	.070
Ethnicity = Asian	r	.033	.044	-.026	-.062	.011
	p	.364	.236	.485	.305	.812
Ethnicity = Hispanic	r	-.048	-.138**	-.108**	-.148*	-.039
	p	.187	.000	.004	.014	.381
Ethnicity = Caucasian	r	.111**	.140**	.155**	.198**	.101*
	p	.002	.000	.000	.001	.023
Ethnicity = Other	r	-.141**	-.060	-.084*	-.039	-.079
	p	.000	.103	.023	.515	.074
$Level_{enrolled}$ = Freshman	r	.034	.220**	.118**	-.130*	.145**
	p	.350	.000	.001	.030	.001
$Level_{enrolled}$ = Sophomore	r	-.023	-.184**	-.098**	.086	-.113*
	p	.534	.000	.008	.155	.011
$Level_{enrolled}$ = Junior	r	-.025	-.086*	-.055	-.021	-.044
	p	.503	.021	.137	.726	.324
$Level_{enrolled}$ = Senior	r	-.004	-.029	-.001	.112	-.034
	p	.907	.439	.969	.064	.437
$Status_{entry}$ = Freshman	r	.178**	.182**	.169**	.067	.050
	p	.000	.000	.000	.265	.264
$Status_{entry}$ = Transfer	r	-.139**	-.125**	-.124**	-.038	-.050
	p	.000	.001	.001	.524	.263
$Status_{entry}$ = Other	r	-.117**	-.150**	-.124**	-.056	-.008
	p	.001	.000	.001	.350	.851
$\Delta Years_{matriculation}$	r	-.213**	-.292**	-.211**	-.148*	-.315**
	p	.000	.000	.000	.014	.000
$Math_{college}$ = No College Math	r	.042	.292**	.204**	-.039	N/A
	p	.249	.000	.000	.523	
$Math_{college}$ = CollegeAlgebra/ Trig/Pre-Calc	r	-.184**	-.414**	-.301**	-.174**	.048
	p	.000	.000	.000	.004	.278
$Math_{college}$ = Calculus I	r	.047	-.003	.007	.098	-.053
	p	.195	.943	.847	.104	.235
$Math_{college}$ = Calculus II and Above	r	.164**	.198**	.146**	.140*	.041
	p	.000	.000	.000	.020	.358
$Status_{enrolled}$ = First Semester Freshman	r	.261**	.396**	.295**	.216**	.346**
	p	.000	.000	.000	.000	.000
$Status_{enrolled}$ = First Semester Transfer	r	-.087*	-.034	-.033	.100	-.010
	p	.017	.357	.367	.096	.821
$Status_{enrolled}$ = Prior Freshman	r	-.249**	-.242**	-.213**	-.235**	-.206**
	p	.000	.000	.000	.000	.000
$Status_{enrolled}$ = Prior Sophomore	r	-.098**	-.247**	-.164**	.074	-.184**
	p	.007	.000	.000	.222	.000
$Status_{enrolled}$ = Prior Junior or Senior	r	-.024	-.100**	-.066	.034	-.067
	p	.511	.007	.075	.570	.132

**. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level.

Table 26

2007 Correlations Between Demographic or Academic Background Variables and Prior Academic Performance Variables

		HSGPA (n = 625)	ACT math (n = 617)	ACT composite (n = 617)	UGPA (n = 241)	$Math_{grade}$ (n = 418)
Female	r	.248**	-.130**	-.046	.158*	.113*
	p	.000	.001	.250	.014	.020
Ethnicity = African American	r	-.155**	-.046	-.111**	-.166**	-.084
	p	.000	.254	.006	.010	.087
Ethnicity = Asian	r	-.007	-.043	-.077	-.093	-.025
	p	.858	.288	.057	.148	.607
Ethnicity = Hispanic	r	-.032	-.044	-.061	-.030	-.041
	p	.430	.273	.133	.640	.399
Ethnicity = Caucasian	r	.052	.049	.099*	.049	.022
	p	.197	.226	.014	.445	.654
Ethnicity = Other	r	.046	.033	.040	.093	.065
	p	.247	.412	.326	.149	.183
$Level_{enrolled}$ = Freshman	r	.052	.155**	.100*	-.084	.276**
	p	.198	.000	.013	.196	.000
$Level_{enrolled}$ = Sophomore	r	-.103*	-.170**	-.117**	.030	-.159**
	p	.010	.000	.004	.643	.001
$Level_{enrolled}$ = Junior	r	.046	-.005	-.003	.048	-.156**
	p	.246	.906	.934	.458	.001
$Level_{enrolled}$ = Senior	r	.043	-.014	.015	-.006	-.056
	p	.278	.733	.707	.925	.256
$Status_{entry}$ = Freshman	r	.112**	.164**	.152**	.067	.148**
	p	.005	.000	.000	.297	.002
$Status_{entry}$ = Transfer	r	-.093*	-.161**	-.143**	-.082	-.162**
	p	.019	.000	.000	.203	.001
$Status_{entry}$ = Other	r	-.059	-.051	-.057	-.015	-.026
	p	.141	.206	.155	.816	.594
$\Delta Years_{matriculation}$	r	-.177**	-.236**	-.183**	-.086	-.235**
	p	.000	.000	.000	.182	.000
$Math_{college}$ = No College Math	r	.031	.320**	.266**	.097	N/A
	p	.440	.000	.000	.132	
$Math_{college}$ = CollegeAlgebra/ Trig/Pre-Calc	r	-.113**	-.441**	-.375**	-.063	.045
	p	.005	.000	.000	.330	.357
$Math_{college}$ = Calculus I	r	-.030	-.062	-.031	-.094	-.033
	p	.460	.123	.443	.144	.496
$Math_{college}$ = Calculus II and Above	r	.151**	.215**	.164**	.123	-.008
	p	.000	.000	.000	.057	.875
$Status_{enrolled}$ = First Semester Freshman	r	.234**	.336**	.261**	.138*	.352**
	p	.000	.000	.000	.032	.000
$Status_{enrolled}$ = First Semester Transfer	r	-.054	-.106**	-.130**	.073	-.113*
	p	.175	.008	.001	.257	.021
$Status_{enrolled}$ = Prior Freshman	r	-.290**	-.306**	-.241**	-.135*	-.100*
	p	.000	.000	.000	.036	.041
$Status_{enrolled}$ = Prior Sophomore	r	-.135**	-.182**	-.127**	.025	-.139**
	p	.001	.000	.002	.697	.005
$Status_{enrolled}$ = Prior Junior or Senior	r	.057	-.009	.003	.027	-.148**
	p	.154	.824	.940	.676	.002

**. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level.

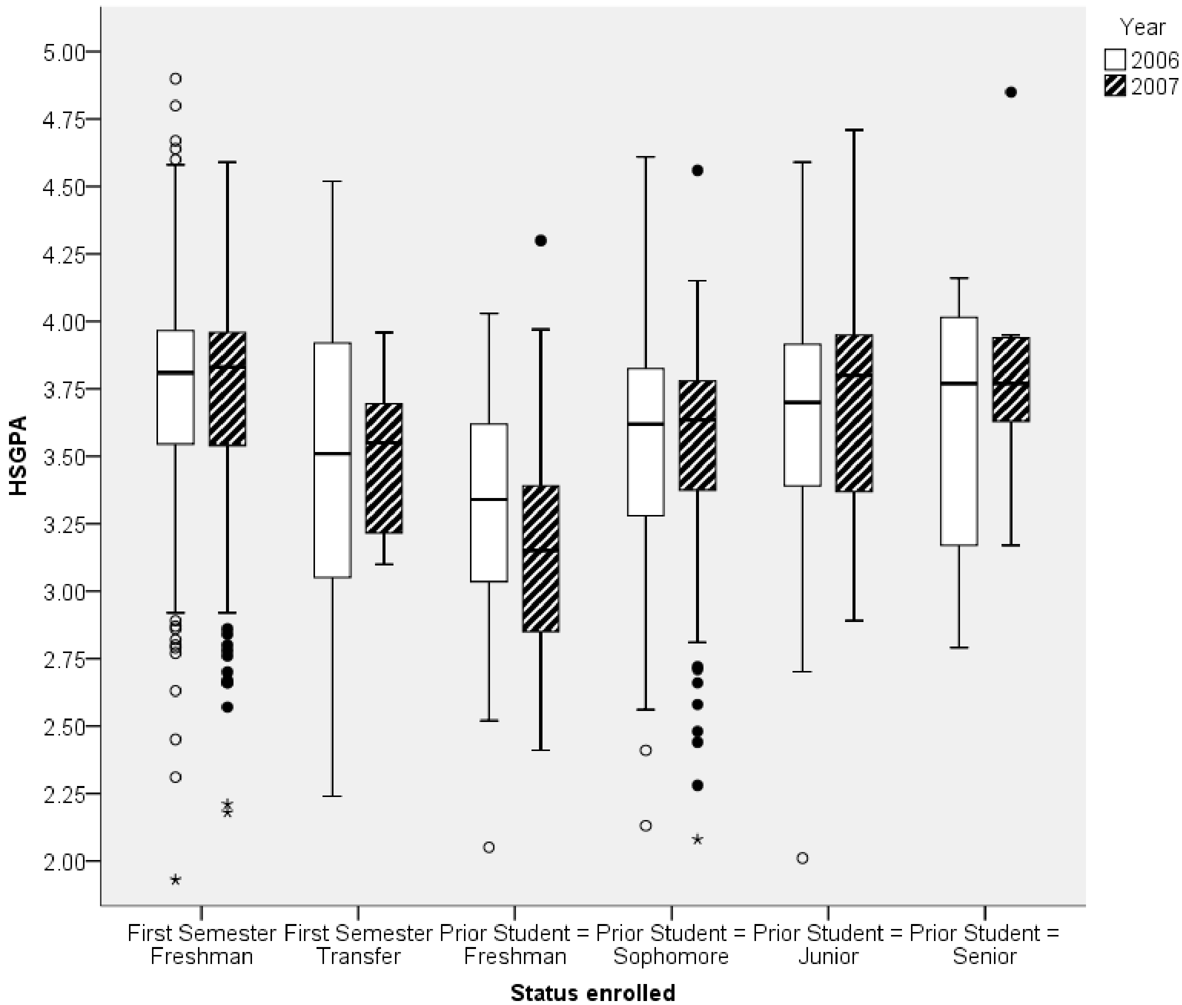


Figure 30 Boxplot showing the mean HSGPA along with its 25% (lower edge of box) and 75% (upper edge of box) quartiles for students in the $Status_{enrolled}$ categories for 2006 and 2007.

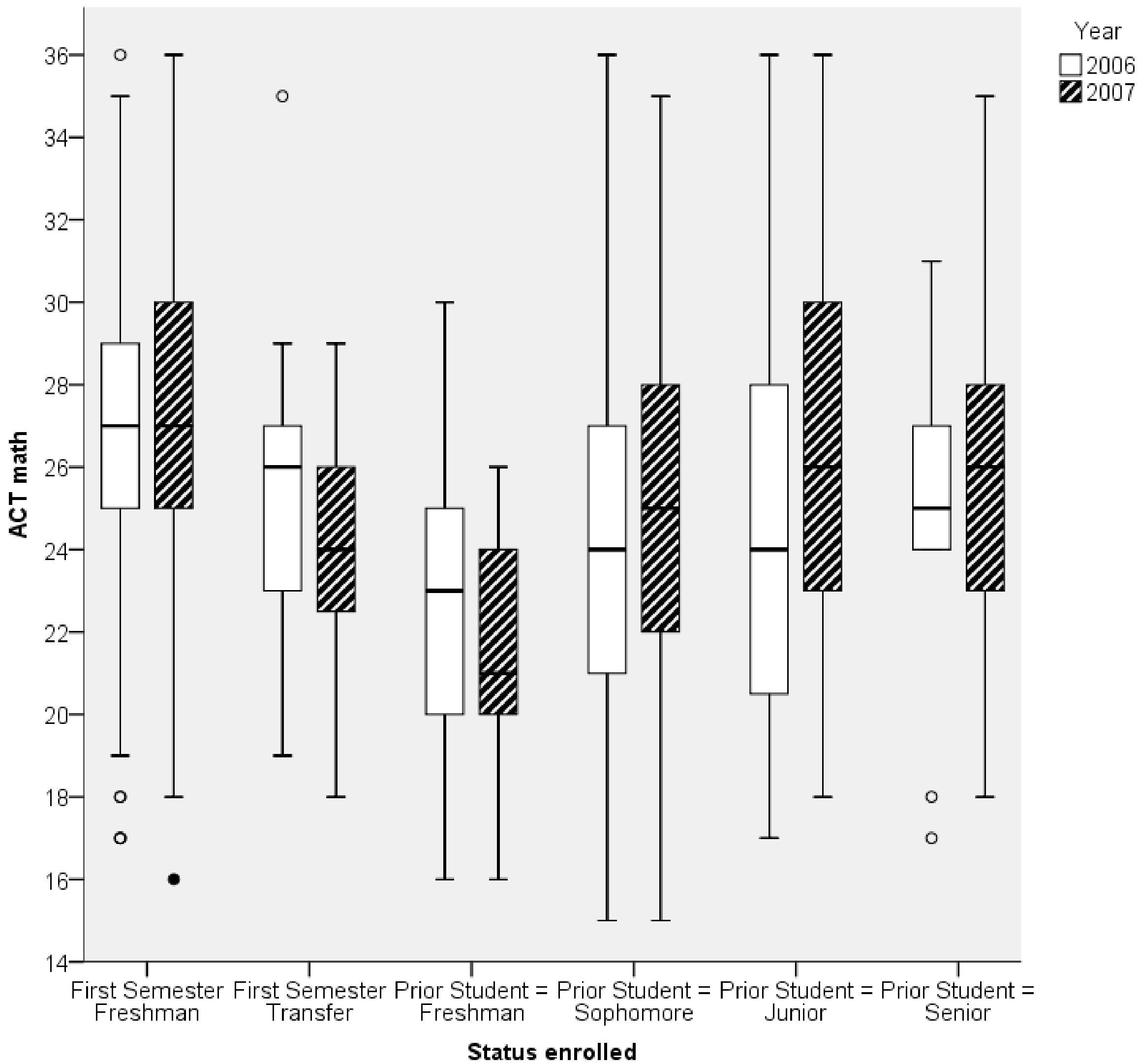


Figure 31Boxplot showing the mean ACT_{math} along with its 25% (lower edge of box) and 75% (upper edge of box) quartiles for students in the $Status_{enrolled}$ categories for 2006 and 2007.

Tutorial Use

All students enrolled in general chemistry in the fall 2006 and 2007 courses had access to the ReMATCH tutorials and homework problems. However, those students in the 2006 experimental group and all students in the 2007 course were required to complete the tutorial for a grade in their lab and lecture, respectively. Table 27 displays a summary of how the *groups of interest* interacted with the ReMATCH website. In the *ReMATCH Log-ins* column, Table 27 shows the percentage of students in each of the *groups of interest* who logged into the tutorial website at least once, the percentage who logged in at least three times, the maximum number of log-ins observed for each group, and the mean number of log-ins observed for the group. The column titled *ReMATCH Problems Attempted* in Table 27 shows the percentage of students who attempted at least one ReMATCH problem, the percentage who attempted at least five problems, the percentage who attempted all 40 problems, the maximum number of problems attempted, and the average number of problems attempted for each *group of interest*.

Overview of Tutorial Use in 2006

In the 2006 comparison group, a quarter of the students logged in to the ReMATCH website at least once, but only 3% recorded three or more ReMATCH log-ins. However, in the experimental group, 98% logged in at least once and 92% logged in at least three times (see Table 27). The average number of log-ins for ReMATCH users was 2.2 (SD = 2.50, n = 146) for the comparison group and 11.4 (SD = 6.29, n = 214) for the experimental group. Table 27 shows that while few students in the comparison group attempted to work any of the ReMATCH homework problems, the percentage of students in the experimental group who attempted the ReMATCH homework problems was much greater. Of those in the experimental group, 94% attempted at least five problems, and 29% attempted all 40 of the homework problems. The average number of ReMATCH problems attempted, $\text{ReMATCH}_{\text{attempted}}$, by those in the experimental group was just over 31 (SD = 9.9, n = 214), and the average number of ReMATCH problems answered correctly, $\text{ReMATCH}_{\text{correct}}$, was nearly 27 ($SD$ = 6.3, n = 214).

Table 27

Summary Statistics of ReMATCH Use for Groups of Interest

	ReMATCH Log-ins				ReMATCH Problems Attempted				
	% of Students		User Descriptors		% of Students			User Descriptors	
Groups of Interest	1 or more	3 or more	Max.	Mean (std. dev.)	1 or more	5 or more	All 40	Max.	Mean (std. dev.)
2006 Comparison (n = 562)	25.3%	3.4%	19	2.3 (SD = 2.53)	6.4%	1.7%	--	23	5.2 (SD = 4.51)
2006 Experimental (n = 222)	98.2%	92.3%	37	11.2 (SD = 6.37)	96.8%	94.1%	29.3%	40	31.1 (SD = 9.92)
2007 (n = 672)	100%	98.8%	71	19.2 (SD = 9.51)	99.6%	99.3%	75.7%	40	37.7 (SD = 6.28)

For the comparison and the experimental groups, the distributions of the number of ReMATCH$_{attempted}$ in 2006 did not resemble a normal curve (see the top and middle panels of Figure 32). Because of this lack of normality, ReMATCH$_{attempted}$ was not used as an interval-level variable in any parametric analyses, such as ANOVAs or regression analyses, which assume normally distributed interval-level variables. Therefore, for all further analyses, ReMATCH$_{attempted}$ became a categorical-level variable based on levels of use in the 2006 experimental group. Splitting the ReMATCH$_{attempted}$ variable for the 2006 experimental group into three groups of approximately equal size formed the following categories:

(1) attempted 5-28 problems (34% of experimental group),

(2) attempted 29-38 problems (30% of experimental group), and

(3) attempted 39-40 problems (36% of experimental group).

ReMATCH$_{attempted}$ also contained a fourth category to represent the 2006 comparison group, simply titled *comparison group*. The categorical-level version of ReMATCH$_{attempted}$ was used in all further ANOVA analyses, while dichotomized versions of each of these categories were used in further correlation and regression analyses. It is important to note that a goal for this study was to have *all* experimental students attempt *all* of the ReMATCH homework assignments; this is why the ReMATCH problems were included as graded assignments for the experimental group. Therefore, these studies only considered students who attempted 39-40 ReMATCH homework problems to have used ReMATCH as it was designed to be used.

Many students in the experimental section attempted problems multiple times before finding the correct answer. For those in 2006 who attempted 39-40 problems, the *number of total attempts* ranged from 76 – 424 with a mean of 201 (SD = 88.1, n = 77), and the average number of *attempts per problem* ranged from 2 – 11 with a mean of 5. While attempting each of these 39-40 problems, students also logged into the ReMATCH website multiple times, the *number of log-ins* ranged from 4 to 37 with a mean of 13 (SD = 6.02, n = 77). The bar graphs in Figure 33 show the average $\text{ReMATCH}_{\text{correct}}$, *number of log-ins*, and *attempts per problem* for each of the three categories of ReMATCH users from the 2006 experimental group.

Overview of Tutorial Use in 2007

When the ReMATCH tutorial was a requirement for all students in 2007, student interaction with the ReMATCH website and homework problems was much greater. For the 2007 group, 100% of the students logged in at least once, and nearly 99% logged in more than three times. The average *number of log-ins* by students in the 2007 group was 19 (SD = 9.5, n = 672), and the maximum number of log-ins was 71. Nearly all of the students in this group, over 99%, tried more than five ReMATCH homework problems; and a vast majority of the students in 2007, nearly 76%, tried all 40 ReMATCH problems. Out of the students in the 2007 group who tried any ReMATCH homework problems, the average for $\text{ReMATCH}_{\text{attempted}}$ was nearly 38 (SD = 6.3, n = 672). The average $\text{ReMATCH}_{\text{correct}}$ was nearly 37 (SD = 7.4, n = 672), just below the average number of ReMATCH problems attempted for this group.

A goal of the 2007 study, as it was for the 2006 study, was for students to attempt all the ReMATCH homework assignments; and, therefore, only those students who attempted 39-40 problems were considered to have used the tutorial as it was designed to be used. A much greater portion of the students assigned to complete ReMATCH in 2007 met this goal than in 2006. For those students who attempted 39-40 problems, the *number of total attempts* in 2007 ranged from 42 to 629, extending both the upper and lower ends of the range seen in 2006. Overall, the mean *number of total attempts* for students in this group decreased by nearly 30 attempts between years to nearly 173 attempts (*SD* = 83.0, *n* = 546) in 2007. The average number of *attempts per problem* ranged from 1 to 16 with a mean of 4. These values extended the upper end of the range seen in 2006, but actually produced a lower mean number of attempts in 2007. The *number of log-ins* ranged from 5 to 71 with an average of 20 (*SD* = 9.4, *n* = 546), resulting in an average increase of seven log-ins from 2006 to 2007.

While the ReMATCH website consisted of tutorial pages for students to reference when attempting the ReMATCH homework problems during both years of this study, the actual number of tutorial pages increased between 2006 and 2007, to a maximum of 88 tutorial content pages in 2007. As described in the Methods, the content of the tutorial pages did not change between 2006 and 2007 but longer explanations were split across multiple pages to make the website more user-friendly in the 2007 version. In addition, in 2007, a method of recording which tutorial pages students visited was implemented. Data on the tutorial pages each student viewed confirmed that at least some students viewed some of the ReMATCH tutorial pages while working the ReMATCH homework assignments. Over 92% viewed at least one tutorial page, and nearly 85% viewed over five tutorial pages. Approximately 25% of the students in 2007 visited at least 44 pages, one-half of the tutorial pages, while 6.8% visited at least 66 pages, three-fourths of the tutorial pages. The average number of *unique content pages viewed* by all students in the 2007 group was nearly 29, roughly one-third of the pages, (*SD* = 21.5, *n* = 672). Some students returned to a particular tutorial page multiple times during the semester. The average number of times students visited each unique tutorial page, average *views per tutorial page*, was determined by dividing the *total number of pages viewed* by the number of *unique content pages viewed*. The mean of *views per tutorial page* for each student in 2007 was 1.8 (*SD* = 1.03, ranging from 0 to 7.3 views per page).

The histogram in Figure 34 displays the distribution of the number of *unique content pages viewed* in 2007. Based on a visual inspection of this graph, the distribution of *unique content pages viewed* was not modeled well by a normal curve. The number of students who accessed between 0 and

36 unique content pages were fairly equal, but above 36 pages is where students viewing greater proportions of the tutorial pages decreased quickly. Due to this lack of normality, this variable split into a categorical variable by creating quartiles of ReMATCH users based on the number of pages they viewed. This resulted in the following levels for Content Pages Viewed:

(1) 0-10 Pages Viewed (24% of 2007 ReMATCH users),

(2) 11-26 Pages Viewed (26% of 2007 ReMATCH users),

(3) 27-43 Pages Viewed (25% of 2007 ReMATCH users), and

(4) 44 or More Pages Viewed (25% of 2007 ReMATCH users).

Correlation and regression analyses used dichotomized versions of the categories of the Content Pages Viewed variable.

The distribution of $\text{ReMATCH}_{\text{attempted}}$ by students in 2007 was more skewed than that in 2006 due to the large portion of the students in 2007 who tried all 40 ReMATCH problems (see the bottom panel of Figure 32). However, for consistency purposes, the $\text{ReMATCH}_{\text{attempted}}$ variable in 2007 was split into the same three categories that were used for the 2006 experimental group: 5-28 Problems (6.8%), 29-38 Problems (11.3%), and 39-40 Problems (81.8%). Again, dichotomized versions of this variable were used in further analyses. The bar graphs in Figure 35 show the average $\text{ReMATCH}_{\text{correct}}$, number of log-ins, attempts per problem, and content pages viewed for each of these three categories of ReMATCH users.

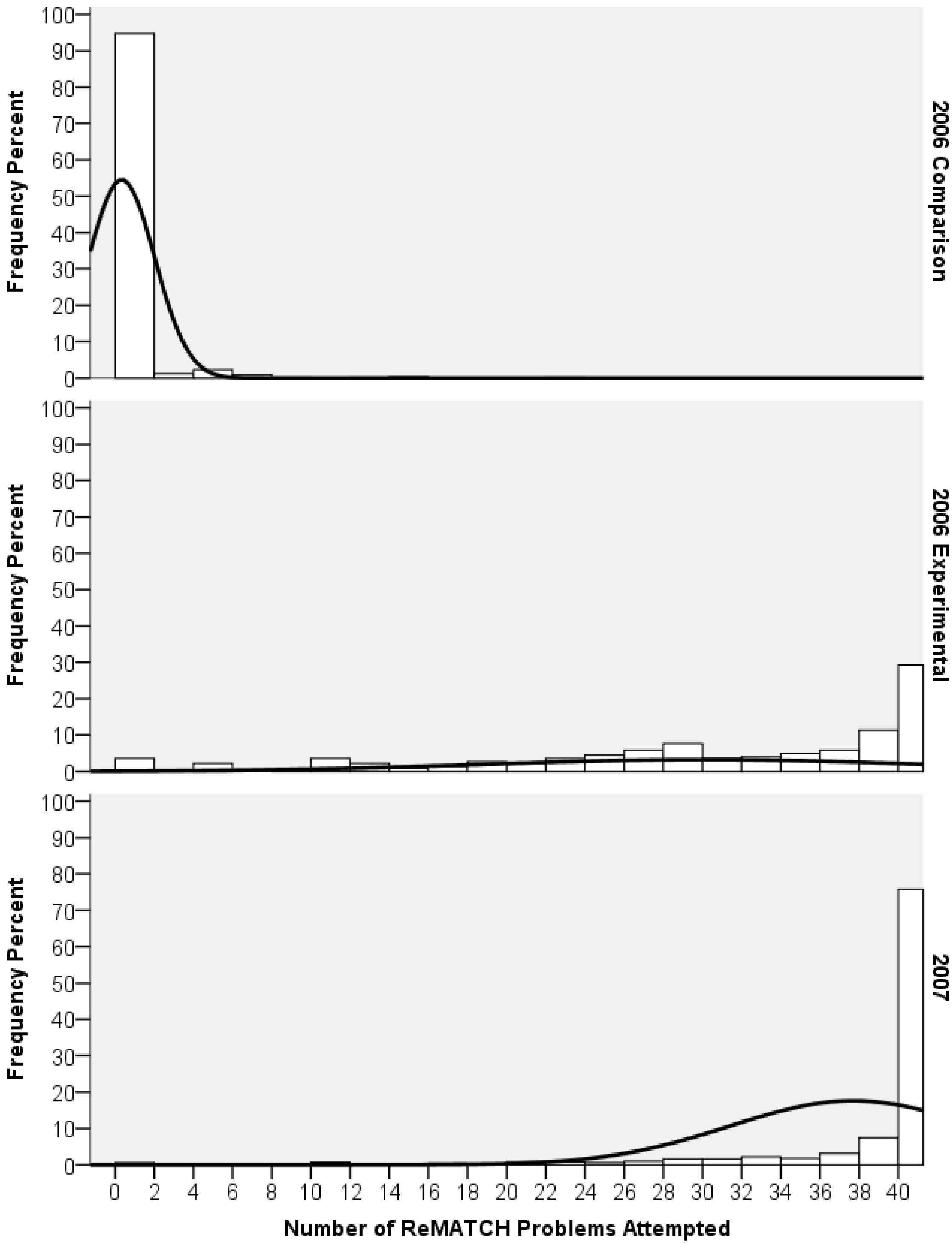


Figure 32 Histograms displaying the distribution of $ReMATCH_{attempted}$ for each group of interest. Based on these non-normal distributions, $ReMATCH_{attempted}$ was not used as an interval-level variable in any analyses, instead it was divided into a categorical variable.

2006

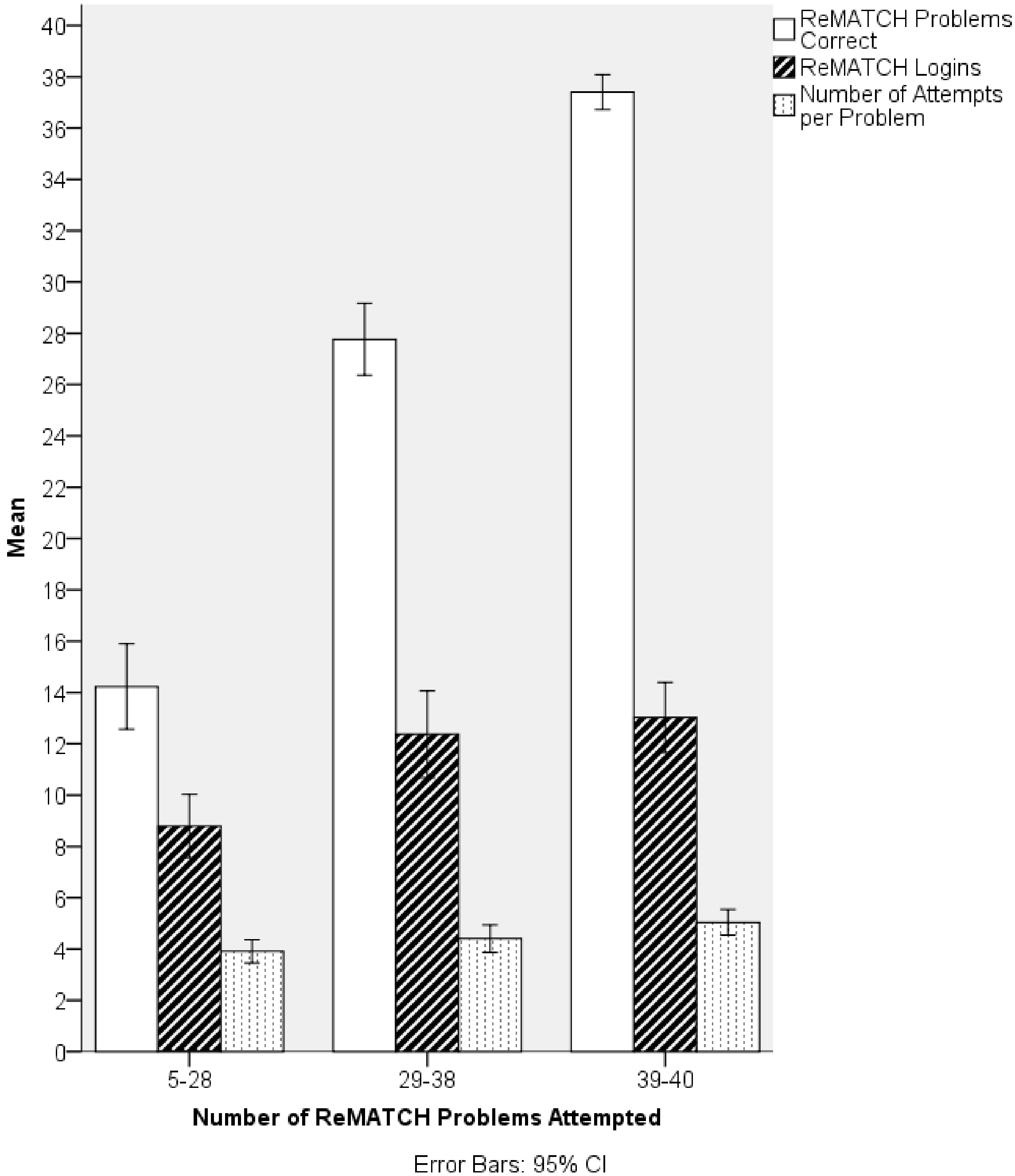


Figure 33 Bar graph comparing ReMATCH$_{correct}$, number of log-ins, and attempts per problem for the ReMATCH$_{attempted}$ categories in 2006.

2007

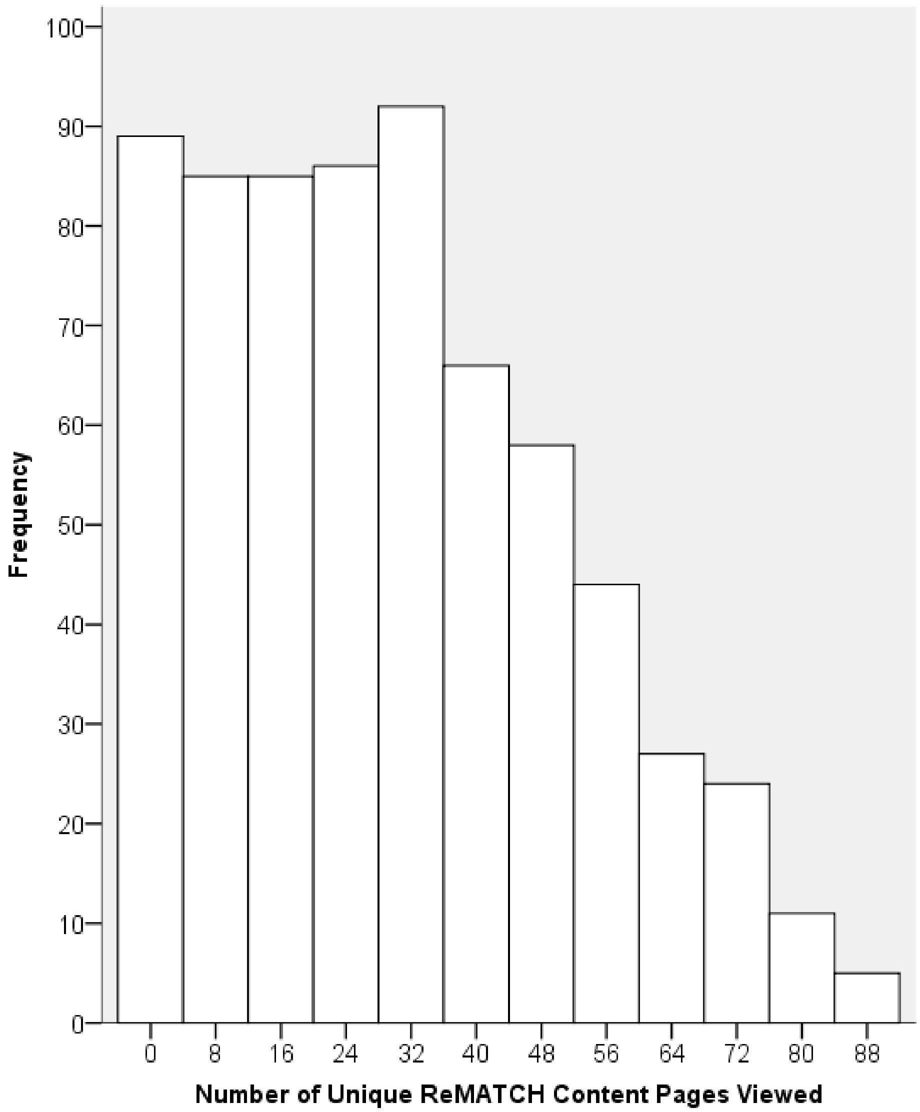


Figure 34 Histogram displaying the distribution of ReMATCH content pages viewed by students in 2007.

2007

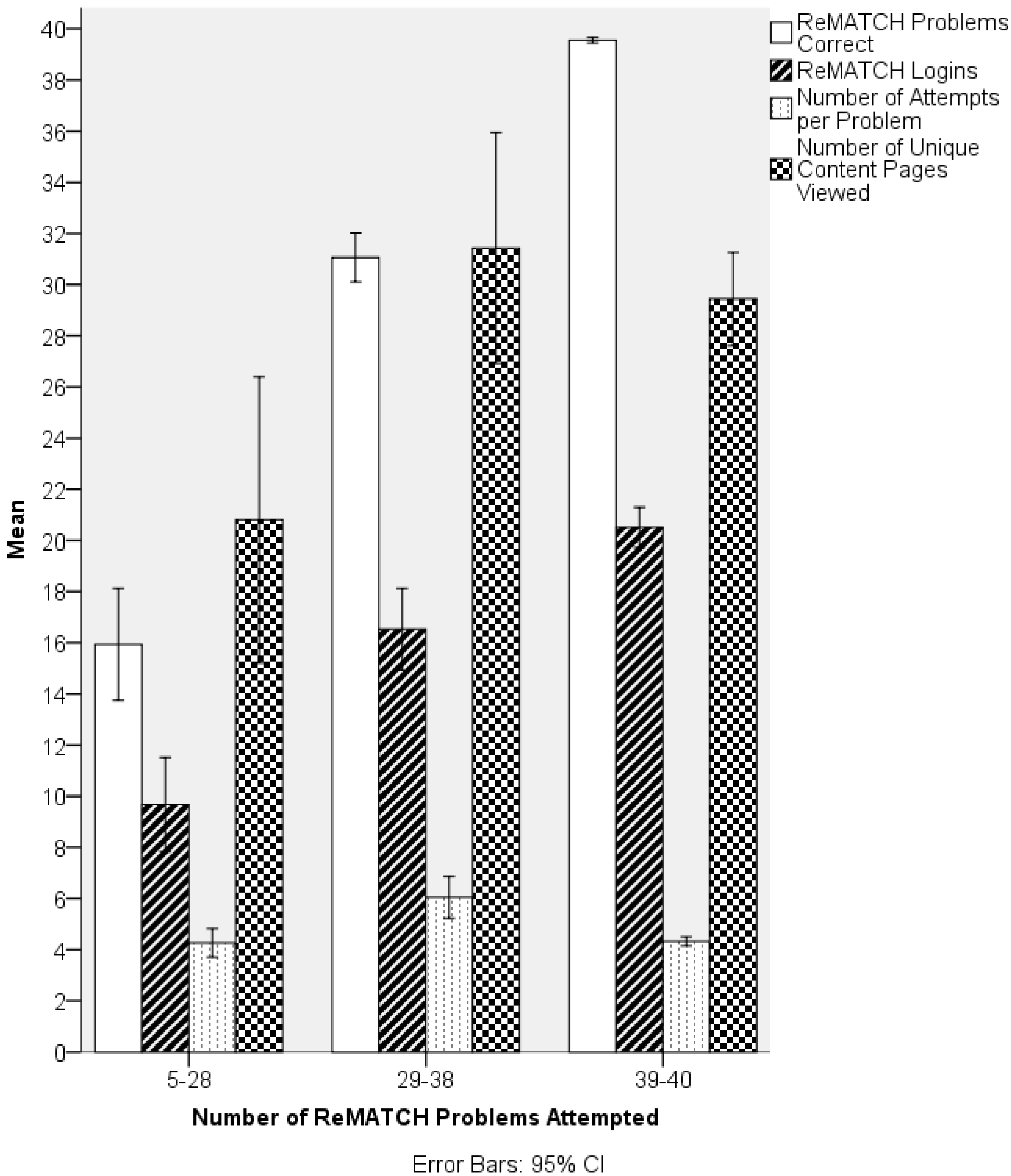


Figure 35 Bar graph comparing $\text{ReMATCH}_{\text{correct}}$, number of log-ins, and attempts per problem for the $\text{ReMATCH}_{\text{attempted}}$ categories in 2006.

Correlations Between Tutorial Use Variables

Separate bivariate correlations were conducted for the different tutorial-use variables in the 2006 experimental and 2007 groups to determine whether any of these measures were highly correlated with each other and, thus, redundant. For both years, the tutorial-use measures included *number of log-ins*, $\text{ReMATCH}_{\text{attempted}}$, $\text{ReMATCH}_{\text{correct}}$, and *total number of attempts*. Additionally, in 2007, the measures also included *content pages viewed* and *total pages viewed* (see Table 28). The four tutorial-use measures in 2006 shared significant medium to strong correlations with each other. In 2007, these first four variables continued to share significant correlations with each other, but all of the correlations involving the total number of attempts decreased greatly in strength. The two additional variables present for the 2007 study also shared significant positive correlations with most of the other variables, while correlating most strongly with each other, $r = .86$. The *content pages viewed* and *total pages viewed* variables were least related to the $\text{ReMATCH}_{\text{correct}}$ variable. *Content pages viewed* shared only a weak correlation with $\text{ReMATCH}_{\text{correct}}$ ($r = .10$, $p = .012$), while *total pages viewed* did not correlate significantly with $\text{ReMATCH}_{\text{correct}}$ at all ($r = .06$, $p = .155$). Both variables shared weak correlations with $\text{ReMATCH}_{\text{attempted}}$.

The largest correlations between any of the tutorial-use variables for both the 2006 experimental and 2007 groups existed between $\text{ReMATCH}_{\text{attempted}}$ and $\text{ReMATCH}_{\text{correct}}$, sharing a strong positive correlation of $r = .94$ in 2006 and $r = .97$ in 2007. To reduce the use of redundant variables in further analyses, one variable was selected for exclusion from any pair of variables sharing a correlation coefficient greater than $r = .5$. Therefore, when taking the results of the 2006 and 2007 correlations together, the following variables were the only tutorial-use measures that continued to be used in further analyses: (1) $\text{ReMATCH}_{\text{attempted}}$, (2) *content pages viewed*, and (3) *number of log-ins*.

Table 28

Correlations Within Tutorial-Use Variables for 2006

		ReMATCH Logins	ReMATCH Attempted	Total Attempts	ReMATCH Correct
ReMATCH Logins	*r*	1	.380**	.493**	.367**
	p		.000	.000	.000
	n	214	214	214	214
ReMATCH Attempted	*r*		1	.620**	.942**
	p			.000	.000
	n		214	214	214
Total Attempts	*r*			1	.597**
	p				.000
	n			214	214
ReMATCH Correct	*r*				1
	p				
	n				214

Correlations Within Tutorial-Use Variables for 2007

		ReMATCH Logins	ReMATCH Attempted	Total Attempts	ReMATCH Correct	Content Pages Viewed	Total Pages Viewed
ReMATCH Logins	*r*	1	.346**	.375**	.335**	.355**	.382**
	p		.000	.000	.000	.000	.000
	n	672	672	672	672	672	672
ReMATCH Attempted	*r*		1	.263**	.969**	.135**	.089*
	p			.000	.000	.000	.021
	n		672	672	672	672	672
Total Attempts	*r*			1	.185**	.330**	.323**
	p				.000	.000	.000
	n			672	672	672	672
ReMATCH Correct	*r*				1	.097*	.055
	p					.012	.155
	n				672	672	672
Content Pages Viewed	*r*					1	.856**
	p						.000
	n					672	672
Total Page Views	*r*						1
	p						
	n						672

**. Correlation is significant at the 0.01 level.
*. Correlation is significant at the 0.05 level.

Background Versus Tutorial Use

ANOVAs Comparing Background and Tutorial Use Variables for 2006

An attempt was made to understand whether the students self-selecting into the different categories of the $\text{ReMATCH}_{\text{attempted}}$ variable started the course with significantly different backgrounds. To address this concern, separate one-way ANOVAs were conducted with each dichotomous and interval-level demographic and academic background variable as a dependent variable and the categorical-version of $\text{ReMATCH}_{\text{attempted}}$ as the independent variable. Table 29 shows the percentage of students in $\text{ReMATCH}_{\text{attempted}}$ category for each dichotomous background and level-related background variable. Table 30 shows the means and standard deviations of students in each $\text{ReMATCH}_{\text{attempted}}$ category for each performance- and time-related interval-level background variable. These tables show that the students in the different categories of $\text{ReMATCH}_{\text{attempted}}$ displayed significant differences for a number of these variables. Table 29 shows that of the 19 demographic and level-related background variables, the percent of students across the categories of $\text{ReMATCH}_{\text{attempted}}$ differed significantly for seven variables:

Ethnicity = Other,

$\text{Level}_{\text{enrolled}}$ (interval),

$\text{Status}_{\text{entry}}$ = Freshman,

$\text{Status}_{\text{entry}}$ = Transfer,

$\text{Math}_{\text{college}}$ = No College Math,

$\text{Math}_{\text{college}}$ = College Algebra/ Trigonometry/ Pre-Calculus, and

$\text{Status}_{\text{enrolled}}$ = First Semester Freshman.

Each of these variables lacked homogeneity of variance between the different categories of $\text{ReMATCH}_{\text{attempted}}$; therefore, the Welch *F*-statistics was used to determine the significance of these ANOVAs. The effect size for each of these significant results was, however, small. As assessed by η^2, the $\text{ReMATCH}_{\text{attempted}}$ variable accounted for less than 2% of the variance in each of these background variables. Table 30 shows that of the six performance- and time-related background variables the mean for the $\text{ReMATCH}_{\text{attempted}}$ categories differed significantly for four of them:

HSGPA,

UGPA,

ACT_{math}, and

$ACT_{composite}$

Each of these variables exhibited homogeneity of variance between the different groups of $ReMATCH_{attempted}$; therefore, the traditional *F*- statistic was used to determine the significance of the ANOVAs. While the effect sizes, as assessed by η^2, of these significant findings were larger than those seen for the last set, they were still small in magnitude. $ReMATCH_{attempted}$ accounted for only between 2-6% of the variance in each prior performance-related measure.

Follow-up pairwise comparisons to these significant ANOVAs were conducted to determine in which categories of $ReMATCH_{attempted}$ the significant differences appeared. The Dunnett C correction was employed when determining the significance of comparisons when a variable lacked homogeneity of variance, while the Bonferroni correction was used when homogeneity was present. According to these post-hoc comparisons, most differences between the $ReMATCH_{attempted}$ categories for these variables existed between the low and high end of the ReMATCH users in the experimental group – those attempting 5-28 problems versus those attempting 39-40 problems. Specifically, this was true for the following background variables:

$Level_{enrolled}$,

$Status_{entry}$ = Freshman and Transfer,

$Math_{college}$ = College Algebra/Trig/Pre-Calculus,

$Status_{enrolled}$ = First Semester Freshman,

HSGPA,

UGPA,

ACT_{math}, and

$ACT_{composite}$.

Because students attempting 39-40 ReMATCH problems were the only ones who used the tutorial as it was designed to be used in 2006, it is of particular interest to note that the comparison group and the attempted 39-40 problems group only differed significantly on four background variables: Ethnicity = Other, HSGPA, UGPA, and ACT_{math}. Significant differences between the comparison group and the low-end of ReMATCH users (the attempted 5-28 problems group) were present for only four variables, $Level_{enrolled}$, $Status_{enrolled}$ = First Semester Freshman, ACT_{math}, and $ACT_{composite}$; and, significant differences between the comparison group and the attempted 29-38 problems group occurred for only one variable, $Math_{college}$ = No College Math. Finally, differences between the attempted 29-38 problems group and the attempted 39-40 problems group were present for just two variables, $Math_{college}$ = No College Math and HSGPA.

Table 29

Summary Statistics and ANOVA Results for Demographic and Academic-Level Background Variables Comparing Separate Categories of ReMATCH$_{attempted}$ in 2006

Demographic and Academic-Level Background Variables		Percent of Students in Each Category of ReMATCH$_{attempted}$			
Variable	Variable Categories	2006 Comp. Group(n=570)	Attempted 5-28 (n = 73)	Attempted 29-38 (n = 64)	Attempted 39-40 (n = 77)
Gender	Female	49.6	48.0	48.4	52.0
	Male	50.4	52.0	51.6	48.0
ANOVA Results[a]	Gender	F (3, 780) = 0.094,		p = .96,	$\eta^2 < .001$
Ethnicity	African American	4.4	6.8	6.3	1.3
	Asian	8.8	5.5	4.7	10.4
	Hispanic	3.9	4.1	6.3	--
	Caucasian	77.0	78.1	81.3	87.0
	Other	6.0	5.5	1.6	1.3
ANOVA Results[a]	African American[b]	F (3, 146.9) = 1.94,		p = .13,	$\eta^2 = .004$
	Asian[b]	F (3, 147.4) = 1.10,		p = .35,	$\eta^2 = .003$
	Hispanic[b]	*not calculated due to missing values in one group*			
	Caucasian[b]	F (3, 144.5) = 1.92,		p = .13,	$\eta^2 = .006$
	Other[b]	**F (3, 166.8) = 3.61,**		**p = .015,**	**$\eta^2 = .006$**
Level$_{enrolled}$	Freshman	67.7	53.4	65.6	67.5
	Sophomore	24.7	31.5	28.1	23.4
	Junior	6.7	11.0	4.7	5.2
	Senior	0.90	4.1	1.6	3.9
ANOVA Results[a]	**Level$_{enrolled}$[b] (interval)**	**F (3, 139.1) = 3.62,**		**p = .015,**	**$\eta^2 = .016$**
Status$_{entry}$	Freshman	89.6	78.1	85.9	94.8
	Transfer	8.4	19.2	10.9	3.9
	Other	2.0	2.7	3.2	1.3
ANOVA Results[a]	**Freshman[b]**	**F (3, 140.5) = 3.45**		**p = .018,**	**$\eta^2 < .001$**
	Transfer[b]	**F (3, 141.3) = 3.26,**		**p = .023,**	**$\eta^2 < .001$**
	Other	F (3, 780) = 0.27,		p = .85,	$\eta^2 = .001$
Math$_{college}$	No College Math	36.8	30.1	18.8	44.1
	Col.Alg/Trig/PreCal	33.0	43.8	40.6	20.8
	Calculus I	22.8	19.2	25.0	20.8
	Calculus II & Above	7.4	6.9	15.6	14.3
ANOVA Results[a]	**No College Math[b]**	**F (3, 143.8) = 4.99,**		**p = .003,**	**$\eta^2 < .001$**
	CollegeAlg/Trig/PreCal[b]	**F (3, 140.9) = 3.91**		**p = .010,**	**$\eta^2 = .001$**
	Calculus I	F (3, 780) = 0.28,		p = .84,	$\eta^2 = .001$
	Calculus II & Above[b]	F (3, 134.1) = 1.88,		p = .14,	$\eta^2 = .011$
Status$_{enrolled}$	First Sem Freshman	62.8	43.9	54.7	68.8
	First Sem Transfer	4.4	13.7	6.3	2.6
	Prior Freshman	7.7	8.2	10.9	3.9
	Prior Sophomore	18.3	21.9	21.9	18.2
	Prior Junior/Senior	6.8	12.3	6.2	6.5
ANOVA Results[a]	**First Sem. Freshman[b]**	**F (3, 139.9) = 4.16,**		**p = .007,**	**$\eta^2 < .001$**
	First Sem Transfer[b]	F (3, 137.6) = 2.18,		p = .094,	$\eta^2 = .016$
	Prior Freshman[b]	F (3, 142.9) = 1.13,		p = .34,	$\eta^2 = .003$
	Prior Sophomore[b]	F (3, 138.4) = 0.30,		p = .83,	$\eta^2 = .001$
	Prior Junior/Senior[b]	F (3, 138.2) = 0.66,		p = .58,	$\eta^2 = .004$

a. ANOVA results shown in **bold** are significant at the $\alpha = .05$ level.
b. The Welch F-statistic was used to determine significance due to heterogeneity of variance.

Table 30

Summary Statistics and ANOVA Results for Performance- and Time-Related Academic Background Variables Comparing Separate Categories of ReMATCH$_{attempted}$ in 2006

Performance & Time-Related Academic Background Variables			Mean and Standard Deviation for Each Category of ReMATCH$_{attempted}$			
			2006 Comp. Group	Attempted 5-28	Attempted 29-38	Attempted 39-40
HSGPA		*M*	3.66	3.45	3.66	3.86
		SD	0.419	0.378	0.352	0.325
		n	541	68	62	75
ANOVA Results[a]	**HSGPA**		**F (3, 742) = 12.77,**		**p < .001,**	**η^2 = .049**
UGPA		*M*	2.91	2.73	3.00	3.38
		SD	0.641	0.560	0.644	0.554
		n	196	31	25	24
ANOVA Results[a]	**UGPA**		**F (3, 272) = 5.33,**		**p = .001,**	**η^2 = .056**
ACT$_{math}$		*M*	25.9	24.3	26.1	27.2
		SD	3.88	4.10	3.51	4.21
		n	529	67	60	74
ANOVA Results[a]	**ACT$_{math}$**		**F (3, 726) = 6.53,**		**p < .001,**	**η^2 = .026**
ACT$_{composite}$		*M*	25.5	24.1	25.2	26.3
		SD	3.62	3.48	3.50	3.73
		n	529	67	60	74
ANOVA Results[a]	**ACT$_{composite}$**		**F (3, 726) = 4.45,**		**p = .004,**	**η^2 = .018**
Math$_{grade}$		*M*	3.1	3.0	3.0	3.2
		SD	0.90	0.99	0.83	0.78
		n	363	51	53	43
ANOVA Results[a]	Math$_{grade}$		F (3, 506) = 0.78,		p = .50,	η^2 = .005
ΔYears$_{entry}$		*M*	0.43	0.67	0.48	0.38
		SD	0.791	0.973	0.734	0.744
		n	570	73	64	77
ANOVA Results[a]	ΔYears$_{entry}$[b]		F (3, 139.9) = 1.61,		p = .19,	η^2 = .008

a. ANOVA results shown in **bold** are significant at the α = .05 level.
b. The Welch F-statistic was used to determine significance due to heterogeneity of variance.

ANOVAs Comparing Background and Tutorial Use Variables for 2007

As in 2006, separate one-way ANOVAs were conducted on the demographic and academic background variables for students who self-selected into the different $\text{ReMATCH}_{\text{attempted}}$ categories in 2007 to gain a better understanding of whether students in these groups were significantly different prior to taking general chemistry. Table 31 shows the percentage of students in each $\text{ReMATCH}_{\text{attempted}}$ category for the dichotomous demographic and level-related background variables, while Table 32 shows the means and standard deviations of students in the $\text{ReMATCH}_{\text{attempted}}$ categories for each performance- and time-related interval-level background variable. Both Table 31 and Table 32 also report the ANOVA results for each dichotomous and interval-level background variable. Of the 19 demographic and level-related background variables, one-way ANOVAs specified that the following seven dependent variables differed significantly across the $\text{ReMATCH}_{\text{attempted}}$ categories (Table 31):

Ethnicity = Other,

$\text{Status}_{\text{entry}}$ = Freshman,

$\text{Status}_{\text{entry}}$ = Transfer,

$\text{Math}_{\text{college}}$ = No College Math,

$\text{Status}_{\text{enrolled}}$ = First Semester Freshman,

$\text{Status}_{\text{enrolled}}$ = First Semester Transfer, and

$\text{Status}_{\text{enrolled}}$ = Prior Junior or Senior.

Most of these variables lacked homogeneity of variance between the different categories of $\text{ReMATCH}_{\text{attempted}}$; the only one with homogeneous variance was $\text{Status}_{\text{enrolled}}$ = First Semester Freshman. For the ANOVAs of the variables lacking homogeneity of variance, the Welch *F*-statistics was used to determine the significance; otherwise, the traditional *F*-statistic was used. While larger than those seen for these variables in 2006, the effect size for each of these significant results was still small when assessed by η^2. The $\text{ReMATCH}_{\text{attempted}}$ variable accounted for between 2 – 8% of the variance in each of these background variables.

ANOVAs of all six of the performance- and time-related academic background variables showed that all of these variables differed significantly across $ReMATCH_{attempted}$ categories (Table 32):

HSGPA,

UGPA,

ACT_{math},

$ACT_{composite}$,

$Math_{grade}$, and

$\Delta Years_{entry}$.

Most of these variables exhibited homogeneity of variance between the different categories of $ReMATCH_{attempted}$; the only one lacking homogeneous variance was $\Delta Years_{entry}$. Again, either the traditional *F*-statistic or the Welch *F*-statistic was used where appropriate. The effect size of two variables, UGPA and $Math_{grade}$, were shown by η^2 to be of medium strength. The $ReMATCH_{attempted}$ variable accounted for 12 – 14% of the variance in these two variables, respectively. The other variables only exhibited small effect sizes, with $ReMATCH_{attempted}$ accounting for 2 – 7% of the variance present in HSGPA, ACT_{math}, $ACT_{composite}$, and $\Delta Years_{entry}$.

Follow-up pairwise comparisons to these 13 significant ANOVAs were conducted to determine which categories of $ReMATCH_{attempted}$ differed significantly for each variable. The Dunnett C correction was employed when determining the significance of comparisons when a variable lacked homogeneity of variance, and the Bonferroni correction was used when homogeneity was present. According to these post-hoc comparisons, eight of these 13 variables possessed significant differences between those students attempting 39-40 problems and each of the other two levels of ReMATCH user (attempting 5-28 problems and attempting 29-38 problems):

$Status_{entry}$ = Freshman,

$Math_{college}$ = No College Math,

$Status_{enrolled}$ = First Semester Freshman,

HSGPA,

UGPA,

ACT_{math},

$Math_{grade}$, and

$\Delta Years_{entry}$.

Only one variable, HSGPA, exhibited significant differences between all levels of ReMATCH users present in 2007 because, in addition to the significant differences present in the above-mentioned groups, HSGPA also exhibited a significant difference between the group attempting 5-28 problems and the group attempting 29-38 problems. Five of the variables with significant ANOVAs only exhibited significant differences in a single pairwise comparison. Four of these were between the group attempting 29-38 and the group attempting 39-40 and included the following: Ethnicity = Other, $Status_{entry}$ = Transfer, and $Status_{enrolled}$ = First Semester Transfer and Prior Junior or Senior. The last variable with only one significant difference was $ACT_{composite}$, and it differed significantly between the group attempting 5-28 problems and the group attempting 39-40 problems.

Table 31

Summary Statistics and ANOVA Results for Demographic and Academic-Level Background Variables Comparing Separate Categories of ReMATCH$_{attempted}$ in 2007

Demographic and Academic-Level Background Variables		Percent of Students in Each Category of ReMATCH$_{attempted}$		
Variable	Variable Categories	Attempted 5-28 (n = 46)	Attempted 29-38 (n = 76)	Attempted 39-40 (n = 550)
Gender	Female	45.6	35.5	48.2
	Male	54.4	64.5	51.8
ANOVA Results[a]	Gender[b]	F (2, 89.8) = 2.27,	p = .11,	η^2 = .006
Ethnicity	African American	2.2	1.3	1.5
	Asian	2.2	6.6	6.4
	Caucasian	84.8	82.9	83.5
	Hispanic	4.4	7.9	2.0
	Other	6.5	1.3	6.6
ANOVA Results[a]	African American	F (2, 665) = 0.081,	p = .92,	$\eta^2 < .001$
	Asian	F (2, 665) = 0.67,	p = .51,	η^2 = .002
	Caucasian	F (2, 665) = 037,	p = .96,	$\eta^2 < .001$
	Hispanic[b]	F (2, 80.6) = 1.93,	p = .15,	η^2 = .013
	Other[b]	**F (2, 103.9) = 4.98,**	**p = .009,**	**η^2 = .002**
Level$_{enrolled}$	Freshman	52.2	42.1	72.3
	Sophomore	32.6	29.0	18.9
	Junior	13.0	18.4	7.3
	Senior	2.2	10.5	1.5
ANOVA Results[a]	Level$_{enrolled}$ (interval)	F (2, 665) = 25.5,	p < .001,	η^2 = .071
Status$_{entry}$	Freshman	73.91	77.63	91.94
	Transfer	13.04	17.11	4.21
	Other	13.04	5.26	3.85
ANOVA Results[a]	**Freshman[b]**	**F (2, 81.1) = 7.48,**	**p = .001,**	**η^2 = .038**
	Transfer[b]	**F (2, 79.8) = 5.53,**	**p = .006,**	**η^2 = .034**
	Other[b]	F (2, 82.7) = 1.72,	p = .19,	η^2 = .012
Math$_{college}$	No College Math	23.9	25.0	40.8
	CollegeAlg/Trig/PreCal	41.3	32.9	28.2
	Calculus I	28.3	27.6	18.5
	Calculus II	6.5	14.5	12.5
ANOVA Results[a]	**No College Math[b]**	**F (2, 93.2) = 6.61,**	**p = .002,**	**η^2 = .017**
	CollegeAlg/Trig/PreCal[b]	F (2, 87.6) = 1.70,	p = .19,	η^2 = .006
	Calculus I[b]	F (2, 85.9) = 2.23,	p = .11,	η^2 = .008
	Calculus II[b]	F (2, 94.1) = 1.34,	p = .27,	η^2 = .003
Status$_{enrolled}$	First Sem Freshman	30.5	34.2	68.8
	First Sem Transfer	6.5	11.8	2.4
	Prior Freshman	19.6	7.9	5.9
	Prior Sophomore	28.3	22.4	15.6
	Prior Junior/Senior	15.2	23.7	8.4
ANOVA Results[a]	**First Sem. Freshman**	**F (2, 665) = 27.9,**	**p < .001,**	**η^2 = .077**
	First Sem. Transfer[b]	**F (2, 79.6) = 3.62,**	**p = .031,**	**η^2 = .026**
	Prior Freshman[b]	F (2, 83.1) = 2.72,	p = .072,	η^2 = .018
	Prior Sophomore[b]	F (2, 85.2) = 2.42,	p = .095,	η^2 = .009
	Prior Junior or Senior[b]	**F (2, 82.7) = 5.11,**	**p = .008,**	**η^2 = .026**

a. ANOVA results shown in **bold** are significant at the α = .05 level.
b. The Welch F-statistic was used to determine significance due to heterogeneity of variance.

Table 32

Summary Statistics and ANOVA Results for Performance- and Time-Related Academic Background Variables Comparing Separate Categories of ReMATCH$_{\mathbf{attempted}}$ in 2007

Performance- and Time-Related Academic Background Variables			Mean and Standard Deviation for Each Category of ReMATCH$_{attempted}$		
Variable			Attempted 5-28	Attempted 29-38	Attempted 39-40
HSGPA		*M*	3.31	3.54	3.69
		SD	0.396	0.364	0.393
		n	41	66	514
ANOVA Results[a]	**HSGPA**		***F* (2, 618) = 21.7,**	***p* < .001,**	**η^2 = .066**
UGPA		*M*	2.59	2.70	3.17
		SD	0.589	0.517	0.569
		n	30	40	170
ANOVA Results[a]	**UGPA**		***F* (2, 237) = 21.0,**	***p* < .001,**	**η^2 = .15**
ACT_{math}		*M*	24.1	25.4	26.9
		SD	3.45	3.63	4.06
		n	38	65	511
ANOVA Results[a]	**ACT_{math}**		***F* (2, 611) = 11.6,**	***p* < .001,**	**η^2 = .037**
$ACT_{composite}$		*M*	24.0	25.2	26.1
		SD	3.02	3.22	3.80
		n	38	65	511
ANOVA Results[a]	**$ACT_{composite}$**		***F* (2, 611) = 6.68,**	***p* = .001,**	**η^2 = .021**
$Math_{grade}$		*M*	2.42	2.63	3.30
		SD	0.874	0.975	0.815
		n	36	57	322
ANOVA Results[a]	**$Math_{grade}$**		***F* (2, 412) = 29.2,**	***p* < .001,**	**η^2 = .12**
$\Delta Years_{entry}$		*M*	0.73	0.88	0.40
		SD	0.801	1.326	0.772
		n	46	76	550
ANOVA Results[a]	**$\Delta Years_{entry}$[b]**		***F* (2,85.380) = 9.86,**	***p* < .001**	**η^2 = .037**

a. ANOVA results shown in **bold** are significant at the α = .05 level.
b. The Welch *F*-statistic was used to determine significance due to heterogeneity of variance.

Finally, in 2007, separate one-way ANOVAs were also conducted on the demographic and academic background variables for students who self-selected into the different quartiles of Content Pages Viewed: 0-10 pages, 11-26 pages, 27-43 pages, 44 pages or more. Conducting this analysis provided insight into whether the students in these self-selected groups were significantly different prior to taking general chemistry. Table 33 shows the percentage of students in the Content Pages Viewed quartiles for the dichotomous and level-related background variables, and Table 34 shows the means and standard deviations of students in the Content Pages Viewed quartiles for each performance- and time-related background variable. Both Table 33 and Table 34 also report the ANOVA results for each dichotomous and interval-level background variable. Of the 19 demographic and level-related background variables and the six performance- and time-related academic background variables, one-way ANOVAs specified that only the following three variables differed significantly across the Content Pages Viewed quartiles (Table 33 and Table 34):

Gender,

Ethnicity = Asian, and

$Level_{enrolled}$.

According to the η^2 calculations, the effect size of Content Pages Viewed on each of the variables with a significant ANOVA was small: Content Pages Viewed accounted for only 2% or less of the variance.

Follow-up pairwise comparison of these three variables were conducted using the Dunnett C correction due to their lack of homogeneity of variance. Interestingly, the particular pairings of the Content Pages Viewed quartiles that were significant for these three variables were different for each variable. Gender displayed significant differences between the lowest quartile of Content Pages Viewed, 0-10 pages, and each of the top two quartiles, 27-43 pages and 44 pages or more. However, $Level_{enrolled}$ showed a statistically significant difference only between the second quartile, 11-26 pages, and the top quartile, 44 or more pages. While the Ethnicity = Asian variable had a significant ANOVA, none of the post-hoc pairwise comparisons were significant.

Table 33

Summary Statistics and ANOVA Results for Demographic and Academic-Level Background Variables Comparing Separate Categories of ReMATCH Content Pages$_{viewed}$ in 2007

Demographic and Academic-Level Background Variables		Percent of Students in Each Category of Content Pages$_{viewed}$			
Variable	Variable Categories	0-10 Pages Viewed (*n*=163)	11-26 Pages Viewed (*n*=175)	27-43 Pages Viewed (*n*=165)	44 or More Pgs Viewed (*n*=169)
Gender	Female	34.97	47.43	49.09	54.44
	Male	65.03	52.57	50.91	45.56
ANOVA Results[a]	**Gender[b]**	**F (3, 370.781) = 4.727,**	**p = .003,**	**η^2 = .020**	
Ethnicity	African American	1.23	--	3.64	1.18
	Asian	2.45	6.86	7.88	7.10
	Caucasian	82.21	84.57	82.42	84.62
	Hispanic	3.07	3.43	1.82	2.96
	Other	11.04	5.14	4.24	4.14
ANOVA Results[a]	African American[b]	*not calculated due to missing values in one group*			
	Asian[b]	**F (3, 361.8) = 2.76,**	**p = .042,**	**η^2 = .008**	
	Caucasian	F (3, 668) = 0.21,	p = .89,	η^2 < .001	
	Hispanic	F (3, 668) = 0.29,	p = .83,	η^2 = .001	
	Other[b]	F (3, 366.1) = 2.15,	p = .094,	η^2 = .014	
Level$_{enrolled}$	Freshman	67.48	73.71	66.06	61.54
	Sophomore	23.31	18.29	21.21	22.49
	Junior	7.36	6.29	11.52	10.65
	Senior	1.84	1.71	1.21	5.33
ANOVA Results[a]	**Level$_{enrolled}$[b] (interval)**	**F (3, 370.3) = 2.65,**	**p = .049,**	**η^2 = .012**	
Status$_{entry}$	Freshman	89.57	92.00	90.91	82.84
	Transfer	5.52	5.14	4.24	11.24
	Other	4.91	2.86	4.85	5.92
ANOVA Results[a]	Freshman[b]	F (3, 367.9) = 2.36,	p = .071,	η^2 = .013	
	Transfer[b]	F (3, 367.7) = 2.04,	p = .11,	η^2 = .012	
	Other[b]	F (3, 365.3) = 0.77,	p = .51,	η^2 = .003	
Math$_{college}$	No College Math	37.42	38.86	41.82	33.14
	CollegeAlg/Trig/PreCal	26.38	32.57	29.70	30.77
	Calculus I	23.31	17.71	14.55	24.85
	Calculus II	12.88	10.86	13.94	11.24
ANOVA Results[a]	No College Math[b]	F (3, 370.5) = 0.94,	p = .42,	η^2 = .004	
	CollegeAlg/Trig/PreCal	F (3, 668) = 0.55,	p = .66,	η^2 = .002	
	Calculus I[b]	F (3, 369.4) = 2.49,	p = .060,	η^2 = .011	
	Calculus II	F (3, 668) = 0.32,	p = .81,	η^2 = .001	
Status$_{enrolled}$	First Sem Freshman	58.90	68.57	61.82	55.03
	First Sem Transfer	4.29	2.86	2.42	6.51
	Prior Freshman	9.20	6.29	5.45	7.10
	Prior Sophomore	19.02	14.86	18.79	16.57
	Prior Junior/Senior	8.59	7.43	11.52	14.79
ANOVA Results[a]	First Sem Freshman[b]	F (3, 370.1) = 2.44,	p = .064,	η^2 = .011	
	First Sem Transfer[b]	F (3, 365.7) = 1.26,	p = .29,	η^2 = .007	
	Prior Freshman	F (3, 668) = 0.65,	p = .58,	η^2 = .003	
	Prior Sophomore	F (3, 668) = 0.46,	p = .71,	η^2 = .002	
	Prior Junior/Senior[b]	F (3, 367.8) = 1.83,	p = .14,	η^2 = .009	

a. ANOVA results shown in **bold** are significant at the α = .05 level.
b. The Welch F-statistic was used to determine significance due to heterogeneity of variance.

Table 34

Summary Statistics and ANOVA Results for Performance- and Time-Related Academic Background Variables Comparing Categories of ReMATCH Content Pages$_{\text{viewed}}$ in 2007

Performance- and Time-Related Academic Background Variables			Mean and Standard Deviation for Each Category of Content Pages$_{\text{viewed}}$			
Variable			0-10 Pages Viewed	11-26 Pages Viewed	27-43 Pages Viewed	44 and Above Pages Viewed
HSGPA		*M*	3.58	3.67	3.67	3.67
		SD	0.433	0.387	0.405	0.383
		n	151	166	156	152
ANOVA Results[a]	HSGPA		F (3, 621) = 1.96,		p = .12,	η^2 = .009
UGPA		*M*	2.97	2.88	3.06	3.11
		SD	0.567	0.629	0.641	0.587
		n	60	52	59	70
ANOVA Results[a]	UGPA		F (3, 237) = 1.76,		p = .16,	η^2 = .022
ACT_{math}		*M*	26.7	26.8	26.4	26.2
		SD	3.97	4.06	4.33	3.89
		n	152	161	151	153
ANOVA Results[a]	ACT_{math}		F (3, 613) = 0.59,		p = .63,	η^2 = .003
$\text{ACT}_{\text{composite}}$		*M*	25.7	25.9	26.1	25.8
		SD	3.55	3.93	3.85	3.60
		n	152	161	151	153
ANOVA Results[a]	$\text{ACT}_{\text{composite}}$		F (3, 613) = 0.27,		p = .85,	η^2 = .001
$\text{Math}_{\text{grade}}$		*M*	3.0	3.1	3.1	3.3
		SD	0.95	0.91	0.91	0.84
		n	100	107	98	113
ANOVA Results[a]	$\text{Math}_{\text{grade}}$		F (3, 414) = 1.56,		p = .20,	η^2 = .011
$\Delta\text{Years}_{\text{entry}}$		*M*	0.52	0.39	0.46	0.55
		SD	0.877	0.808	0.837	0.951
		n	163	175	165	169
ANOVA Results[a]	$\Delta\text{Years}_{\text{entry}}$		F (3, 668) = 1.13,		p = .34,	η^2 = .005

a. ANOVA results shown in **bold** are significant at the α = .05 level.

Course Performance

The average GC_{grade} for the sampled students completing general chemistry with a grade of A to F in 2006 was 2.81, just above a B-, ($SD = 0.997$, $n = 784$); and, in 2007, it was 2.69, a bit below a B-, ($SD = 1.03$, $n = 672$). The GC_{grade} of students in the 2006 comparison and experimental groups were very similar with the comparison group having an average of 2.82 ($SD = 0.980$, $n = 562$) and the experimental group having an average of 2.78 ($SD = 1.04$, $n = 222$). The distributions of grades for each *group of interest*, shown in Figure 36, illustrate how similar the grades were overall. These distributions are also very similar to that seen previously for the GC_{grade} of students in 2005. Normal curves model these distributions fairly well. The frequencies of all GC_{grade} earned in 2006 and 2007 are shown in Table 35. The D/F rates calculated from this table were between 10% and 12% for 2006 and 2007, respectively.

While GC_{grade} was the only course performance variable available for the 2005 preliminary study, the availability of data from the course grade book in the 2006 and 2007 studies greatly increased the number of course performance measures available for analysis. The presence of individual exam grades allowed the identification and analysis of students who took the final exam along with all three lecture-exams in 2006 and those who took the final along with *at least* three course exams in 2007. Selecting only those students with grades for the exams that were included in their final course grade removed some of the error present in final course grades when considering all students, thereby more accurately reflecting a student's chemistry knowledge, instead of simply "exam-presence," and resulting in a more meaningful measure of chemistry performance. Table 36 shows the means and standard deviations of the *groups of interest* for five course performance measures: GC_{grade}, Percent Course Points, Percent Exam Points, Percent Homework (representing the percent of total WebAssign® homework points earned), and Percent Attendance. These variables were used as percentages instead of raw scores because the maximum raw scores changed slightly between the 2006 and 2007 study. These truly interval-level variables were preferred over GC_{grade} as the performance measures in further analyses. Table 37 provides a frame of reference for two of these interval-level variables, Percent Course Points and Percent Exam Points, by showing how these variables related to the letter grades earned by students each year. Table 37 also includes the differences in the means of consecutive letter grades for each of these variables (i.e. the difference in mean Percent Exam Points for C students minus D students). According to Table 37, the difference in the mean Percent Course Points between consecutive letter grades ranged from 8.4 – 15.0 percentage points in 2006 and 8.5 – 10.4 percentage points in 2007. For Percent Exam Points, the difference in means ranged from 8.3 – 12.9 percentage points in 2006 and 6.2 – 11.7 percentage points in 2007. Taking the arithmetic average of the differences in the means of Percent Course Points and Percent Exam Points between consecutive letter grades indicated that it took on average 11 percentage points to move up one letter grade in 2006 and 10 percentage points to move up one letter grade in 2007. This value was the same for Percent Course Points and Percent Exam Points within a given year.

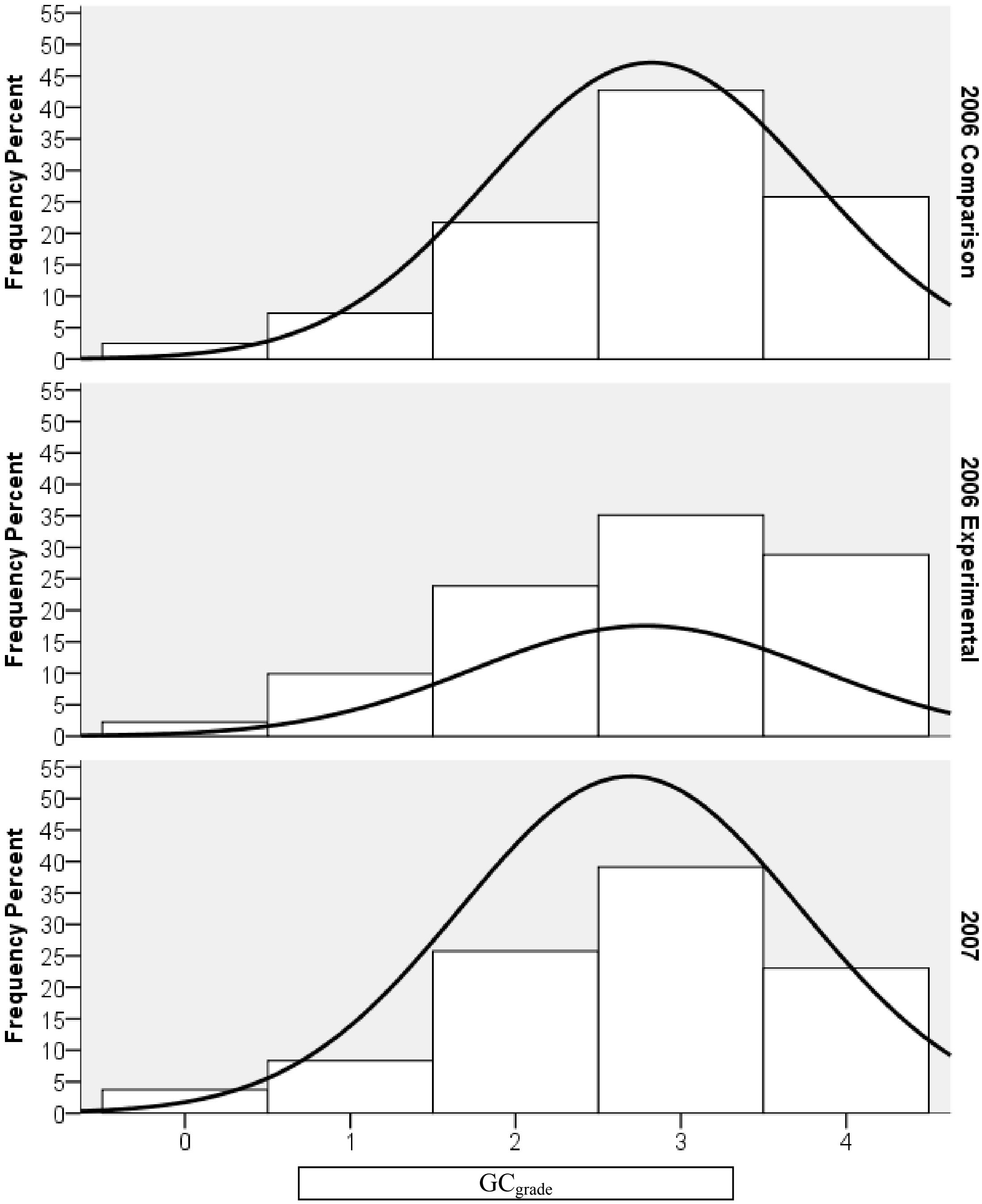


Figure 36Histograms showing the distribution of GC$_{grade}$ for each group of interest. These grade distributions were fairly well modeled by a normal curve.

Table 35

Summary Statistics of GC_{grade} for the *Groups of Interest*

	2006			2007
GC_{grade}	total (n = 784)	comp. (n = 562)	exp. (n = 222)	(n = 672)
A	26.7	25.8	28.8	23.1
B	40.6	42.7	35.1	39.9
C	22.3	21.7	23.9	25.7
D	8.0	7.3	9.9	8.3
F	2.4	2.5	2.3	3.7
Mean (Std. Dev.)	2.81 (0.997)	2.83 (0.980)	2.78 (1.041)	2.69 (1.032)

Table 36

Summary Statistics for Course Performance and Attendance Variables for Students Who Completed the Required Exams for Each *Group of Interest*

Course Performance and Attendance Variables		2006 Comparison (n = 547)	2006 Experimental (n = 219)	2007 (n = 668)
GC_{grade}	Mean	2.9	2.8	2.7
	Std. Dev.	0.89	1.02	1.02
Percent Course Points	Mean	81.9	80.9	80.0
	Std. Dev.	8.78	11.21	10.50
Percent Exam Points	Mean	72.5	72.5	71.4
	Std. Dev.	12.15	14.05	12.56
Percent Homework	Mean	89.0	87.9	82.7
	Std. Dev.	12.94	14.88	16.67
Percent Attendance	Mean	64.1	61.4	48.6
	Std. Dev.	33.23	34.44	28.40
Exam 1 Score	Mean	69.5	70.7	77.2
	Std. Dev.	14.55	15.27	14.25
Exam 2 Score	Mean	71.0	70.0	75.5
	Std. Dev.	12.74	14.33	14.38
Exam 3 Score	Mean	71.2	71.1	67.1
	Std. Dev.	17.48	18.79	16.20
Exam 4 Score	Mean	--	--	63.0
	Std. Dev.	--	--	18.91
Final Exam Score	Mean	151.1	150.5	145.6
		27.72	31.23	28.98

Table 37

Summary Statistics for the Percent Course Points and Percent Exam Points Associated with Each Letter Grade (GC_{grade}) in 2006 and 2007

		Percent Course Points						Percent Exam Points					
		2006 (n = 766)			2007 (n = 668)			2006 (n = 766)			2007 (n = 668)		
GC_{grade}			Min.	Max.		Min.	Max.	.	Min.	Max.		Min.	Max.
A	Mean	91.9	88.0	100	91.9	84.0	99.5	86.8	78.0	99.2	85.7	74.3	95.7
	Std Dev	2.49			2.96			4.30			4.76		
B→A		8.4 percentage pts.			8.6 percentage pts.			12.9 percentage pts.			11.2 percentage pts.		
B	Mean	83.5	78.5	88.1	83.3	73.4	90.1	73.9	60.6	86.2	74.5	59.0	89.8
	Std Dev	2.68			3.19			5.15			5.65		
C→B		10.0 percentage pts.			9.9 percentage pts.			12.5 percentage pts.			10.9 percentage pts.		
C	Mean	73.5	67.6	78.4	73.4	66.9	79.6	61.4	45.8	78.2	63.6	47.3	80.8
	Std Dev	3.0			3.21			6.62			6.77		
D→C		11.0 percentage pts.			10.8 percentage pts.			10.7 percentage pts.			11.7 percentage pts.		
D	Mean	62.5	54.5	67.3	62.6	56.0	67.7	50.7	30.6	74.4	51.9	38.3	67.3
	Std Dev	3.3			2.66			8.96			7.31		
F→D		15.0 percentage pts.			10.4 percentage pts.			8.3 percentage pts.			6.2 percentage pts.		
F	Mean	47.5	35.4	53.9	52.2	43.3	58.3	42.4	25.6	59.4	45.7	27.7	65.5
	Std Dev	7.45			3.59			12.96			8.26		

ANOVAs of Course Performance Variables by Groups of Interest

An ANOVA was conducted comparing the mean GC_{grade} for each of the *groups of interest*. The means and standard deviations of each group can be seen in Table 35. The groups did not exhibit homogeneity of variance according to their significant Levene's Test. Therefore, the Welch *F*-statistic was used to determine the significance of any differences in the mean GC_{grade} for these groups. No significant differences in mean GC_{grade} existed across the groups, F (2, 607.149) = 2.454, p = .087. Separate one-way ANOVAs were also conducted comparing the means of each of the interval-level course performance and attendance variables across the *groups of interest*. The homogeneity of variance assumption was met across the groups for Percent Exam Points, and the ANOVA for this measure indicated that *groups of interest* did not have a significant effect, F (2, 1431) = 1.363, p = .256. For all of the other measures, the homogeneity of variance assumption was not met for the groups, so the Welch *F*-statistic was used to test for any significant differences in the group means. Significant effects from *groups of interest* were present for each of these measures, but the effect size of each was small, with *groups of interest* accounting for only 1-5% of the variance in each variable:

Percent Course Points, F (2, 578.80) = 6.038, p = .003, η^2 = .008,

Percent Homework, F (2, 604.29) = 29.178, p < .00,1 η^2 = .039, and

Percent Attendance, F (2, 571.81) = 41.252, p < .001, η^2 = .053.

Post-hoc comparisons using the Dunnett C correction indicated that the 2006 comparison group and 2007 group differed significantly for all three of these variables and that the 2006 experimental group and the 2007 group differed significantly for two of these variables, Percent Homework and Percent Attendance. Students in the 2006 comparison group had significantly higher mean Percent Course Points, mean Percent Homework, and mean Percent Attendance than those in the 2007 group, and the 2006 experimental group had significantly higher mean Percent Homework and mean Percent Attendance values than those in the 2007 group. No statistically significant differences existed between the 2006 comparison group and the 2006 experimental group for any of the course performance and attendance variables.

Relationship Between Percent Exam Points and GC_{grade}

To determine whether students were performing similarly on the first three course exams each year, ANOVAs comparing the means of each of these three exams and the final exam across the *groups of interest* were conducted. Their results are as follows:

Exam 1	F (2, 1453) = 50.796, $p < .001$,
Exam 2	F (2, 1453) = 25.503, $p < .001$,
Exam 3	F (2, 584.6) = 5.258, $p = .005$, and
Final Exam	F (2, 1453) = 1.442, $p = .237$.

Exams 1, 2, and the Final possessed homogeneity of variance; however, exam 3 did not, so its ANOVA is based on the Welch F- statistic instead of the traditional F-statistic. Means and standard deviations for each exam given in each year are shown in Table 36. The ANOVAs showed that student performance on the three course exams differed significantly between the *groups of interest*, but that performance did not differ significantly between the *groups of interest* on the final exam. Post hoc comparisons conducted using the Bonferroni correction for Exam 1 and Exam 2 and the Dunnett C correction for Exam 3 indicated that scores on all three exams for the 2007 group were significantly different from both those of the 2006 comparison and 2006 experimental groups. The 2007 group scored significantly higher on Exam 1 and Exam 2 but significantly lower on Exam 3 when compared to both 2006 groups. No differences were found to exist between the 2006 comparison and 2006 experimental groups. A difference in the pattern of exam performance was noted between 2006 and 2007 (see Figure 37).

In 2006, there was a consistent improvement in average test score from one exam to the next, including an additional jump in performance on the final. However, in 2007, there was a marked decrease in exam performance over the semester with the final grade representing roughly the average of the other exams. The differences between the 2006 and 2007 groups could be due to the introduction of a fourth exam in 2007.

Correlations Between Course Performance and Attendance Variables

Bivariate correlations between the course performance and attendance variables were conducted to determine how closely related these were to each other and to check for redundancy within these variables for 2006 and 2007 (Table 38). Pairs of variables with correlations greater than $r = .50$ were not used concurrently in further analyses to reduce any problems that might occur due to multi-collinearity between variables. Not surprisingly, all of these variables were significantly and positively correlated. Students' Total Exam Points and GC_{grade} possessed strong significant correlations each year with $r = .88$ - $.89$; this means that 77 – 79% of the variance in GC_{grade} was accounted for by Total Exam Points. While they were all significant, Percent Attendance consistently had lower correlation coefficients with the other variables. Its correlation with Percent Exam Points in 2006 was the only correlation that fell below the $r = .50$ cut-off, $r = .41$. Therefore, for 2006, when Percent Exam Points were used in an analysis, Percent Attendance was also considered for inclusion in the analysis to provide a measure of a students' level of commitment to the general chemistry course. In 2007, correlations between Percent Attendance and the other variables were again weaker than between the other variables, and the correlation between Percent Attendance and Percent Exam Points was the lowest of all, $r = .34$. Therefore, as in 2006, both Percent Attendance and Percent Exam Points were considered for concurrent inclusion in further analyses. Interestingly, the relationship between Percent Exam Points and Percent Homework was the same for both years of the study, $r = .56$, roughly 31% of the variance in Exam Points can be accounted for by the Percent Homework points that students have earned.

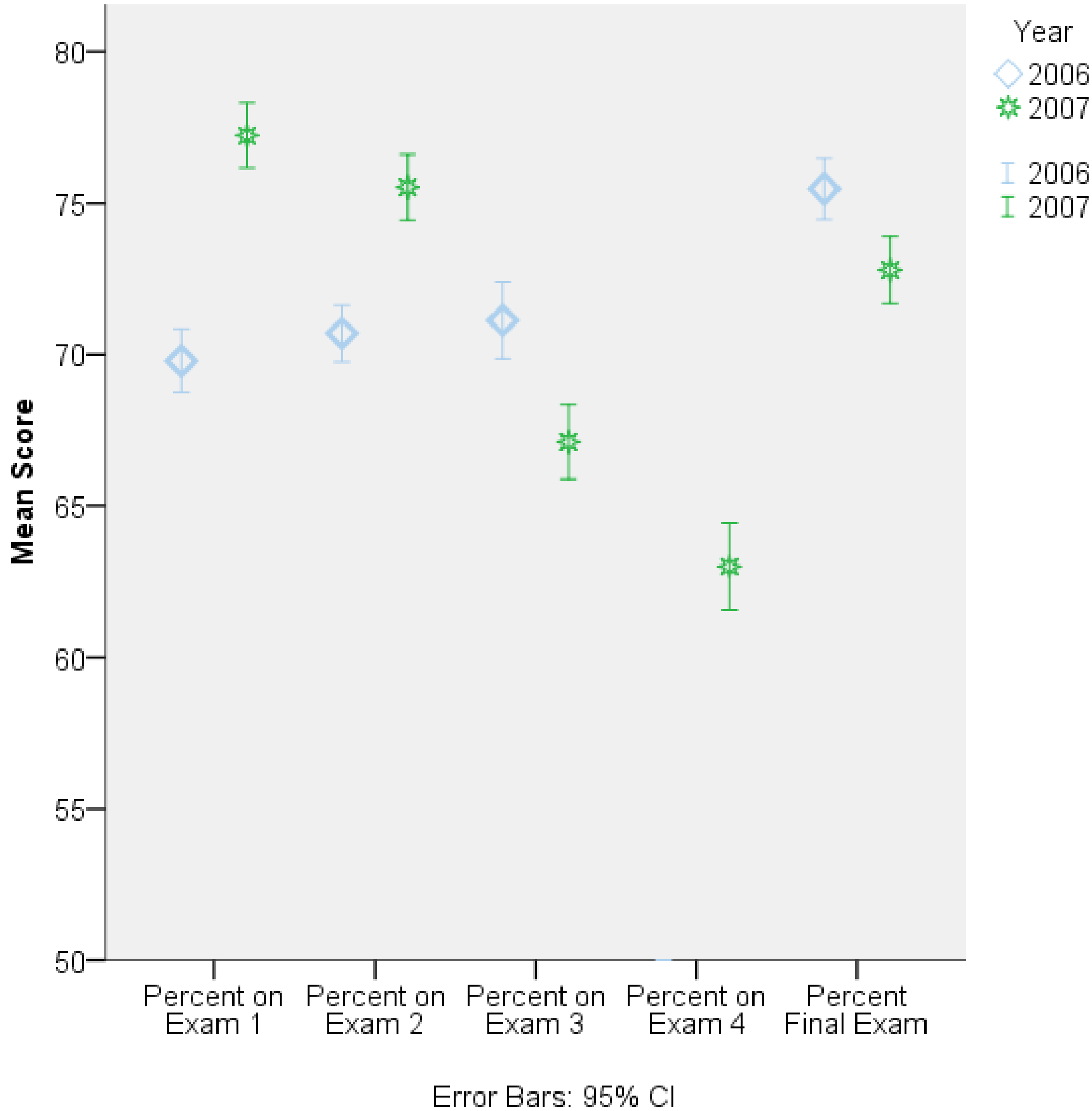


Figure 37 Scatterplot highlighting the difference in the pattern of exam scores across the 2006 and 2007 courses separately.

Table 38

Correlations Within Course Performance Variables for 2006						
2006 (n = 766)		GC_{grade}	Percent Course Points	Percent Exam Points	Percent Homework	Percent Attendance
GC_{grade}	r	1	.95**	.89**	.73**	.53**
	p		.000	.000	.000	.000
Percent Course Points	r		1	.93**	.78**	.56**
	p			.000	.000	.000
Percent Exam Points	r			1	.56**	.41**
	p				.000	.000
Percent Homework	r				1	.51**
	p					.000
Percent Attendance	r					1
	p					

Correlations Within Course Performance Variables for 2007						
2007 (n = 668)		GC_{grade}	Percent Course Points	Percent Exam Points	Percent Homework	Percent Attendance
GC_{grade}	r	1	.95**	.88**	.77**	.44**
	p		.000	.000	.000	.000
Percent Course Points	r		1	.94**	.78**	.46**
	p			.000	.000	.000
Percent Exam Points	r			1	.56**	.34**
	p				.000	.000
Percent Homework	r				1	.42**
	p					.000
Percent Attendance	r					1
	p					

Discussion of Background, Tutorial Use, and Course Performance Data

Identifying Comparable Groups from 2006 and 2007

Based on the lack of demographic and academic background variables displaying any significant differences between the 2006 comparison and 2006 experimental groups in one-way ANOVAs, these two groups were considered to have come from comparable demographic and academic backgrounds for future analyses. ANOVAs identified differences between the 2006 comparison and the 2007 groups, indicating that the overall distribution of students in the KU general chemistry course varies slightly between years in regards to some ethnicity and $Status_{entry}$ categories and some $Math_{college}$ and ACT_{math} levels. However, the effect sizes for these significant differences were weak and, therefore, while significant due to the large sample size, these many not be meaningful effects.

The results of separate correlational analyses of students in the 2006 and 2007 fall course showed that Caucasian students entering KU directly from high school consistently brought with them higher values on measures of previous academic performance and that female students typically reported higher previous grade-related measures, such as while male students typically reported higher previous standardized test scores (Danili & Reid, 2006; Duckworth & Seligman, 2006; Hamilton, 1998; Walding, et al., 1994). A relationship between students' prior $Math_{college}$ level and their previous academic performance measures was also shown in these correlations. Students having no college math displayed higher ACT_{math} and $ACT_{composite}$ scores, but this was most likely due to high ACT_{math} scores being necessary to place out of the prerequisite math courses at KU combined with the fact that most KU students without a prior college math course are traditional, Caucasian first-semester freshmen (other characteristics significantly correlated with higher previous academic performance measures). In addition to students with no prior college math, students whose last math course was calculus II or above also displayed high previous academic performance measures. Not surprisingly, students whose last college math course was simply a prerequisite for calculus (college algebra or pre-calculus) were associated with significantly lower levels of previous academic performance variables. These findings, along with their associated summary statistics, provided a good description of the different types of students enrolling in general chemistry at KU. Additionally, these findings and summary statistics provide other researchers with a good idea of the validity and generalizability of the studies presented here: the quasi-experimental test of ReMATCH in 2006 despite the use of a convenience sample was conducted between comparable (equivalent) groups, and findings from the 2006 and 2007 studies should be generalizable to other populations of general chemistry students consisting primarily of traditional, Caucasian first-semester freshmen.

Comparing ReMATCH-Use Across Implementations

When ReMATCH was integrated for a lab grade for an experimental group in the 2006 study, it was expected that the vast majority of students would use ReMATCH as it was designed to be used and would complete all, or nearly all, of the problems in the ReMATCH homework assignments. The goal when including ReMATCH as a graded assignment for this group of students was to have all experimental students attempt all of these problems. However, in the 2006 experimental group, this was not the case; only 29% of the experimental students attempted all of the ReMATCH homework problems. In the 2007 study, when all students had to complete the ReMATCH homework problems for a grade in lecture, the portion of students attempting all of the problems was must higher, nearly 76%. Based on the negativity expressed by many 2006 experimental group participants regarding having to complete an assignment different from the rest of the class, it is believed that the integration of ReMATCH into the lecture and, thus, its adoption as a requirement for all students, was deemed to be a fairer approach, resulting in less negative associations towards the ReMATCH website. The average number of problems that ReMATCH users tried increased by nearly 23% from 2006 to 2007, and their average number of log-ins increased by 73% from 2006 to 2007. For both the 2006 and 2007 studies, only students who attempted 39-40 ReMATCH homework problems were considered to have used ReMATCH as the intervention was designed to be used; this was 36% of the 2006 experimental group and 81% of the 2007 group. It is interesting to remember that students in the 2006 comparison group also had access to the ReMATCH tutorial as a supplemental, ungraded resource. Under this condition, less than 2% of the students attempted five or more ReMATCH problems. This stark difference with either of the previous values speaks to the necessity that any general chemistry course interventions requiring student-involvement should be included as graded components of the course.

Tutorial-use summary statistics of the 2006 experimental and 2007 groups indicated that most ReMATCH users conducted their work in ReMATCH in multiple settings, an average of 11 sessions in 2006 and 19 sessions in 2007, and that most students attempted each problem multiple times. Because the correctness of an answer for a problem was overwritten in the homework table of the ReMATCH database when students attempted a problem again, it is impossible to know whether the multiple attempts made by each student were made while trying to get the answer correct the first time or after it had been answered correctly by students reviewing the problem set. However, it is probably safest to assume that most attempts were made while students were trying initially to obtain the correct answer. Regardless of this distinction, within the students who attempted 39-40 ReMATCH problems, those in the 2006 experimental group and 2007 group had very similar values for their average attempts per problem, five attempts per problem in 2006 and four attempts per problem in 2007.

Separate bivariate correlations between the measures of tutorial-use from 2006 and 2007 showed that these variables were very interrelated: the more times students logged into ReMATCH, the more problems they attempted, the more attempts they made at individual problems, and the more problems they ultimately answered correctly. The strongest correlations within either year of this data existed between $\text{ReMATCH}_{\text{attempted}}$ and $\text{ReMATCH}_{\text{correct}}$; data from each year had an $r^2 \geq .89$, meaning that nearly 90% of the variance $\text{ReMATCH}_{\text{correct}}$ could be explained by students simply attempting the ReMATCH problems. The additional tutorial-use variables available in 2007, *content pages viewed* and *total pages viewed*, were also significantly correlated with many of the other student tutorial-use variables, such that the more times students logged into ReMATCH and had more interactions with ReMATCH problems, the more unique content pages and the greater the total number of content pages they were likely to view. *Content pages viewed* and *total pages viewed* correlated most strongly with each other, so that students who viewed many pages were also highly likely to view each page multiple times.

Characterizing Different Levels of ReMATCH Users

Because the distribution of ReMATCH$_{attempted}$ with in the 2006 experimental group lacked normality, the variable was split into a categorical variable for use in further analyses in 2006 and 2007. Likewise, because the distribution of *content pages viewed* lacked normality for 2007 ReMATCH users, this variable was also split into a categorical variable for use in further analyses in 2007. Using dichotomized forms of each of these categorical variables, separate ANOVAs were conducted in 2006 and 2007 between ReMATCH$_{attempted}$ or Content Pages Viewed with all of the demographic and academic background variables. These correlational analyses for categories of ReMATCH$_{attempted}$ in 2006 and 2007 revealed that the different categories of users, specifically those with 5-28 Attempted versus those with 39-40 Attempted, displayed significant differences in a number of background variables. In 2006, the background variables for which the effect size for the statistically significant difference was greater than $\eta^2 = .01$ were Status$_{entry,}$ HSGPA, UGPA, ACT$_{math}$, and ACT$_{composite}$. However, all of these are still considered small effect sizes, except for UGPA, which approached a moderate effect size. This analysis showed that students starting KU as freshman, students with high HSGPAs, students with high UGPAs, and students with high ACT scores were all statistically more likely to be in the group with 39-40 Attempted, whereas students starting KU as transfers, students with low HSGPAs, students with low UGPAs, and students with low ACT scores were all statistically more likely to be in the group with 5-28 Attempted. Regarding demographic background variables, these results were very similar for the 2007 group, except that within 2007 a moderate effect size existed for the First Semester Freshman category of the Status$_{enrolled}$ variable. It appears that in 2007 there was a greater effect on tutorial-use related solely to the fact that a student had come to KU and enrolled in chemistry directly out of high school. The effect sizes of the significant differences observed between ReMATCH$_{attempted}$ levels due to academic background variables were larger in 2007 than in 2006; especially of interest were the moderate effect due to HSGPA and the large effect due to UGPA.

The difference from 2006 to 2007 in the strength of the relationships between HSGPA or UGPA and ReMATCH$_{attempted}$ can be attributed in part to the different implementations of ReMATCH in 2006 and 2007, lab versus lecture, respectively. Research on the integration of material across chemistry laboratories and chemistry lectures has previously illustrated that students rarely see a connection between general chemistry laboratories and lectures (Hawkes, 2004; M. T. Oliver-Hoyo, Allen, Hunt, Hutson, & Pitts, 2004). It is possible that in 2006 some students missed the connection between the ReMATCH tutorial assigned in lab and the review material they needed to cover for the lecture portion of the course. Resulting in a more GPA-diverse group of students at each level of $\text{ReMATCH}_{\text{attempted}}$. When in 2007 ReMATCH was integrated into the lecture, its connection to lecture may have been more evident to students. Under these conditions, one would expect students who have performed better previously as demonstrated by their higher GPA values (for both HSGPA and UGPA) to also complete a greater portion of the ReMATCH homework problems because these students have shown prior evidence of a high academic aptitude, the ability to be a good student.

Other interesting comparisons include those made between the ReMATCH users who used the tutorial as it was designed to be used in 2006, $\text{ReMATCH}_{\text{attempted}}$ = 39-40 Problems, and the comparison group for 2006. It is through the comparison of these two groups that the effectiveness of ReMATCH will later be evaluated; therefore, it was necessary to determine how similar these groups were. The ANOVAs discussed above also included the comparison group; their post-hoc pairwise comparisons demonstrated that the two groups only differed significantly on four background variables: HSGPA, UGPA, ACT_{math}, and Ethnicity = Other. Of these, however, only the interval-level variables met the criteria for at least a small effect size, and only the effect size for UGPA approached a moderate level.

The effect of demographic and academic background variables on Content Pages Viewed in the 2007 group presents very different results from those observed for $\text{ReMATCH}_{\text{attempted}}$. None of the interval-level performance-related academic background variables were observed to be significantly different across the categories of Content Pages Viewed via ANOVAs. The only dichotomous demographic variables that varied significantly across the categories and exhibited at least a small effect size were Gender and $\text{Level}_{\text{enrolled}}$. Follow-up pairwise comparisons, indicated that the significant difference observed for Gender existed between the lowest quartile of Content Pages Viewed, 0-10 pages, and each of the top two quartiles, 27-43 pages and 44 pages or more. Significantly more females viewed 27 or more content pages than viewed 0-10 content pages, while significantly more males viewed 0-10 content pages than viewed 27 or more content pages. The follow-up pairwise comparisons for $Level_{enrolled}$ indicated that this interval-level variable differed significantly for those who viewed 11-26 pages and those who viewed 44 or more pages. This is probably a difference between those who needed help but gave up on the tutorial work and those who needed used the tutorial extensively.

Decisions Regarding ReMATCH-Use in Further Analyses

Based on the effect sizes discussed above for the tutorial-use variables, it appears that while there are several differences between students in the 2006 comparison group and the 2006 Attempted 39-40 group, most of these differences result in small effects and, therefore, account for only small portions of the overall variance of the variable. However, despite these small effect sizes, caution was taken in further analyses including the $ReMATCH_{attempted}$ levels through the considered use of covariates. The 2007 results and effect sizes for Content Pages Viewed reveal that this variable provides the most background neutral way to compare the amount of students' interactions with ReMATCH to their course performance, confidence, or attitude towards ReMATCH. By comparison, the categories of $ReMATCH_{attempted}$ show moderate and large effect sizes on some background variables in 2007 and the sample sizes differ significantly between the categories for that year. Therefore, where appropriate, further analyses regarding ReMATCH use in 2007 will be held to examining only the students who Attempted 39-40 ReMATCH homework problems and will differentiate ReMATCH-users based on their Content Pages Viewed. In other analyses, select levels from both $ReMATCH_{attempted}$ and Content Pages Viewed will be included, and the omitted levels will serve as a comparison group.

Considering Course Performance

With average GC_{grade} around a B- and with D/F rates from 10-12%, the grades were very similar between 2006 and 2007. By relating Percent Course Points to the letter grades of GC_{grade}, the typical number of exam points that separated students of consecutive letter grades was determined. In 2006, this ranged from 8-13 points, and, in 2007, this ranged from 6-12 points. No significant differences in GC_{grade}, Percent Exam Points, or Percent Attendance Points were observed between the

2006 comparison and 2006 experimental groups. In future analyses for 2006 and 2007, when the Percent Exam Points variable is used, the Attendance variable is also considered for inclusion to provide a measure of students' commitment to their general chemistry course. However, it will be included as Attendance Points in these further analyses because Attendance Points will be more interpretable than Percent Attendance in multiple linear regression analyses. Also, Percent Exam Points was selected over GC_{grade} and other performance variables for all further analyses because it was deemed to reflect more accurately an individual student's chemistry understanding, as opposed to the student's academic aptitude, his or her ability to be a good student. Other course performance measures, such as GC_{grade} and Percent Course Points, incorporate homework grades and lab grades into their calculations and thereby reflect a student's ability to follow directions and ask their friends for answers as much as they reflect a student's chemistry understanding.

A marked difference was observed in the pattern of test scores between 2006 and 2007. In 2006, students' grades on each exam improved across the semester, while, in 2007, students' lecture exam grades gradually decreased across the semester and then their final exam grade was closer to their overall mean lecture exam grade for the semester. This difference between the 2006 and 2007 groups could be due to the introduction of the fourth exam and the adoption of an exam grade-droping policy in 2007. This change reduced the amount of material on each exam and may have decreased the grade-pressure for the course since students were allowed to drop their lowest exam score. According to Sewell (2004), "evidence suggests that allowing students to drop a grade reduces the ex ante motivation to study." Sewell and other researchers who have studied the effects of dropping the lowest exam score when calculating semester grades have discovered that, in this testing condition, student motivation diminishes over the semester and students consistently have lower average final exam scores (Abraham, 2000; Sewell, 2004). However, because the possibility that the content and item-difficulty could have differed between the exams from 2006 and 2007, the observed differences between these groups could, also, simply be due to the exams themselves not being sufficiently similar to yield meaningful comparisons. When correlations between course performance variables in 2006 and 2007 were considered separately, all of the variables shared significant positive correlations with one another. To reduce the chance of multicollinearity in further analyses, Percent Exam Points and Percent Attendance points were selected as the only course performance variables that would be used concurrently for either year.

Chapter 7

Addressing Hypothesis One from 2006 and 2007 Study

– Results and Discussion of Multiple Linear Regression Analysis

2006 Hypothesis One: Student course performance would differ significantly between students completing the ReMATCH assignments and students using the self-study approach.

2007 Hypothesis One: Student course performance would differ significantly between the groups of students using the ReMATCH tutorial at different levels.

Overview of Procedures Followed When Conducting Multiple Linear Regression Analyses

Separate hierarchical multiple linear regression (MLR) analyses were performed to determine whether the different levels of tutorial-use for each year had any impact on course performance once students' demographic and academic backgrounds and course attendance were considered. A single course performance variable, Percent Exam Points, was chosen as the criterion variable to reflect student course performance for these analyses. To determine which background variables to include as predictor variables in the first step (Model 1) of the MLR analyses, bivariate correlations for each background variable with Percent Exam Points were conducted for each year. The background variables that significantly correlated with Percent Exam Points were considered for use in the MLR analyses along with the Percent Attendance variable, which was included to control for a student's level of commitment to the course. The bivariate correlations are reported in the third column of Table 39 and for 2006 and 2007, respectively.

Because prior research in chemical education has shown that HSGPA and ACT_{math} are two of the best predictors for general chemistry performance, it was determined that these two academic background variables would definitely be included in the first step of the MLR analyses, assuming that their intercorrelation was not too great. However, these two predictors have also been shown through previous ANOVAs in this study to be related to a number of the other background variables present during both years. All of these interrelationships presented the likelihood that some background variables that correlated significantly with Percent Exam Points may have only had that relationship due to also being significantly correlated with HSGPA or ACT_{math}; it was likely that HSGPA or ACT_{math} were acting as mediator variables for some of the other background variables' relationships with Percent Exam Points. To remove this possibility, partial correlation coefficients were computed for the background variables with Percent Exam Points while holding constant the students' HSGPA and ACT_{math} values. These partial correlations are reported in the fourth column of Table 39 and for 2006 and 2007, respectively.

UGPA and $Math_{grade}$ were removed as possible predictor variables in the MLR analyses for both years because each had a small sample size compared to the other background variables. Values for these two background variables were only present for 34 % to 65% of the sampled students each year, while HSGPA and ACT_{math} were present for 92% to 95% of the sampled students each year. In a MLR analysis, only students with values for all included variables are analyzed. Therefore, including UGPA or $Math_{grade}$ would have produced results that were not representative of many of the first semester freshmen students who did not possess prior undergraduate GPAs or prior grades in a college-level math course. Because these first semester freshmen made up the bulk of the sample for each year, it did not make sense to incorporate variables into the models that would cause these students to be removed from the analyses.

Because several of the background variables measured similar student characteristics, bivariate correlations were conducted to look for any possible redundancies between the background variables that had significant partial correlation coefficients with Percent Exam Points while holding HSGPA and ACT_{math} constant. For any pair of background variables that shared a correlational coefficient of $r >$ .50, only one of the variables was chosen for use in the MLR analysis for that year. Because of the slight differences observed previously in the student backgrounds of the 2006 and 2007 samples, the possibility was noted that the set of background variables selected through this method and used as predictors in the MLR analyses could differ between the years of the study. Since the hypotheses reported here do not require comparisons between the two years of this study, this was not a concern.

To form Model 2 in the next step of the hierarchical MLR analyses required the addition of variables reflecting ReMATCH tutorial-use as additional predictors of Percent Exam Points to the previous model. The change in the R^2 value (ΔR^2) between the first and second Models ($\Delta R^2 = R^2_{Model\ 2} - R^2_{Model\ 1}$) indicated whether the addition of the tutorial use variables increased the amount of variance in Percent Exam Points explained by Model 2. A significant ΔR^2, as determined by a significant change in the *F*-value from Model 1 to Model 2, provided evidence that the level of ReMATCH tutorial use had an impact on student course performance above and beyond that predicted by background and attendance variables. Initially for 2006, tutorial use as described by membership in the experimental group variable, $\text{Experimental}_{2006}$, was included in this second step. However, simply being assigned to the experimental group did not have a significant impact on Percent Exam Points over and above that contributed by the background and attendance variables. Students in the experimental group interacted with the ReMATCH tutorial to very different degrees. Therefore, $\text{Experimental}_{2006}$ was removed as a predictor variable and all three of the experimental group levels of $\text{ReMATCH}_{\text{attempted}}$ were added into Model 2 of the MLR analysis, as better measures of students' levels of tutorial use in 2006. When the MLR analysis was conducted for the 2007 study, only the dichotomous variables representing the upper and lower quartiles of Content Pages Viewed and the upper and lower $\text{ReMATCH}_{\text{attempted}}$ levels, Attempted 5-28 and Attempted 39-40, were added in Model 2 of the MLR analysis since no comparison group had been isolated as part of the design for the 2007 study.

Correlations Between Background Variables and Percent Exam Points for 2006

Bivariate correlation coefficients for background and attendance variables with Percent Exam Points (Table 39 show that HSGPA and ACT_{math} are the two background variables with the strongest relationships to Percent Exam Points. Of the other 25 variables, 18 were significantly correlated with Percent Exam Points in these bivariate correlations. However, an examination of the partial correlation coefficients shows that only four of these variables – (1) Female, (2) African American, (3) Hispanic, and (4) Attendance Points – were significantly correlated with the criterion once the effects of HSGPA and ACT_{math} were held constant. This supports the idea that HSGPA and/or ACT_{math} acted as mediators of the bivariate relationships between Percent Exam Points and the other 14 background variables that were no longer significant predictors in the partial correlations. Table 40 shows the significant relationships that were present in the bivariate correlations among HSGPA, ACT_{math}, and the four variables that were significantly correlated with Percent Exam Points in the partial correlations. However, none of these correlation coefficients were greater than r = .50, so none of these variables were likely to be redundant or cause multicollinearity concerns in the MLR analysis. Therefore, all six of these variables were selected for inclusion in Model 1 of the MLR Analysis for 2006.

Table 39

2006 Bivariate Correlations Between Percent Exam Points and Background Data and Related Partial Correlations Controlling for HSGPA and ACT_{math}

Independent Variables		Bivariate Correlation (unless noted, n = 766)	Partial Correlation (df = 701)
		Dependent Variable	
		Percent Exam Points	Percent Exam Points
HSGPA (n = 729)	*r*	.459**	Effects Partialed Out
	p	.000	
ACT_{math} (n = 714)	*r*	.494**	Effects Partialed Out
	p	.000	
$ACT_{composite}$ (n = 714)	*r*	.419**	.002
	p	.000	.961
Female	*r*	-.080*	-.110**
	p	.027	.004
African American	*r*	-.129**	-.077*
	p	.000	.040
Asian	*r*	.070	.039
	p	.054	.297
Hispanic	*r*	-.122**	-.081*
	p	.001	.032
Caucasian	*r*	.101**	.068
	p	.005	.073
Other Ethnicity	*r*	-.052	-.038
	p	.147	.310
$Level_{enrolled}$ = Fresh.	*r*	.119**	.004
	p	.001	.907
$Level_{enrolled}$ = Soph.	*r*	-.105**	-.036
	p	.004	.346
$Level_{enrolled}$ = Junior	*r*	-.038	.036
	p	.294	.345
$Level_{enrolled}$ = Senior	*r*	-.006	.049
	p	.866	.194

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 39 – continued

2006 Bivariate Correlations Between Percent Exam Points and Background Data and Related Partial Correlations Controlling for HSGPA and ACT_{math} (continued)

Independent Variables		Bivariate Correlation (unless noted, n = 766)	Partial Correlation (df = 701)
		Dependent Variable	
		Percent Exam Points	Percent Exam Points
$Status_{entry}$ = Freshman	r	.160**	-.033
	p	.000	.385
$Status_{entry}$ = Transfer	r	-.148**	.032
	p	.000	.403
$Status_{entry}$ = Other	r	-.055	.009
	p	.127	.821
$\Delta Years_{entry}$	r	-.183**	-.016
	p	.000	.674
$Math_{college}$ = None	r	.127**	.014
	p	.000	.711
$Math_{college}$= ColAlg/Trig/PreCalc	r	-.262**	-.064
	p	.000	.090
$Math_{college}$ = Calc I	r	.064	.059
	p	.076	.120
$Math_{college}$ = Calc II and Above	r	.127**	-.013
	p	.000	.724
$Status_{enrolled}$ = First Sem. Freshman	r	.249**	.018
	p	.000	.633
$Status_{enrolled}$ = First Sem. Transfer	r	-.101**	.023
	p	.005	.542
$Status_{enrolled}$ = Prior Freshman	r	-.169**	-.045
	p	.000	.233
$Status_{enrolled}$ = Prior Sophomore	r	-.114**	-.023
	p	.002	.542
$Status_{enrolled}$ = Prior Jr. or Sr.	r	-.038	.032
	p	.298	.395
Attendance Points	r	.406**	.326**
	p	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 40

2006 Correlations[a] Between Possible Predictor Variables for MLR Analysis

n = 705		HSGPA	ACT_{math}	Female	African American	Hispanic	Attendance Points
HSGPA	*r*	1	.401**	.225**	-.085*	-.048	.293**
	p		.000	.000	.023	.202	.000
ACT_{math}	*r*		1	-.233**	-.151**	-.122**	.147**
	p			.000	.000	.001	.000
Female	*r*			1	.066	.073	.079*
	p				.080	.052	.037
African American	*r*				1	-.043	-.057
	p					.258	.128
Hispanic	*r*					1	-.109**
	p						.004
Attendance Points	*r*						1
	p						

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. Listwise *n*=705

MLR Analysis for Effect of Background, Attendance, and Tutorial-Use on Percent Exam Points for 2006

A multiple linear regression analysis was conducted to predict the Percent Exam Points from demographic (Female, African American, and Hispanic) and academic background (HSGPA and ACT_{math}) variables and Percent Attendance Points. The results of this analysis indicated that these predictor variables accounted for a significant amount (nearly 41%) of the Percent Exam Points students earned, R^2 = .41 (adj. R^2 = .40), F (6, 698) = 80.14, p < .001 (Model 1, Table 41). The coefficients from this analysis (Model 1, Table 43) indicated that generally,

(1) students with higher HSGPA, ACT_{math}, and Percent Attendance Points values earned higher values for Percent Exam Points and

(2) female students performed slightly more poorly than their male classmates with equivalent values for HSGPA, ACT_{math}, and Percent Attendance Points.

Coefficients for the African American and Hispanic variables were not significant in this model.

A second analysis was conducted to evaluate whether assignment to the experimental group predicted Percent Exam Points over and above the background and attendance variables. $Experimental_{2006}$ did not account for a significant proportion of the Percent Exam Points after controlling for the effects of background and attendance variables, R^2 change = .41 (adj. R^2 change = .40), F (1, 697) = 1.12 , p = .290 (Model 2,Table 41). Therefore, this variable was removed from the analysis for 2006.

A third analysis was conducted to evaluate whether levels of $ReMATCH_{attempted}$ for students in the experimental group – Attempted 5-28 Problems, Attempted 29-38 Problems, and Attempted 39-40 Problems – predicted Percent Exam Points beyond that predicted by the background and attendance variables. Including these three dichotomous measures of level of tutorial use accounted for a significant proportion of the Percent Exam Points after controlling for the effects of background and course attendance, R^2 change = .43 (adj. R^2 change = .42), F (3, 695) = 7.55, p < .001 (Model 2, Table 42). The coefficients from this analysis (Model 2, Table 43) indicated that, for students with similar background and attendance values, those in the experimental group who attempted 39-40 ReMATCH problems earned more Percent Exam Points than students in the comparison group did. In addition, those in the experimental group who attempted only 5-28 ReMATCH problems, generally, earned fewer Percent Exam Points than similar students in the comparison group. The non-significant coefficient for students in the experimental group who attempted 28-39 problems indicated that these students did not differ from their equivalent counterparts in the comparison group. Using the coefficients from this final model in Table 43, the MLR equation for Predicted Percent Exam Points based on the 2006 data is provided as Equation 2.

$$\begin{aligned}\text{2006 Predicted}\\ \text{Percent Exam Points} = \; & 72.98 + 8.36 * {}_{\text{centered}}\text{HSGPA} + 0.91 * {}_{\text{centered}}\text{ACT}_{\text{math}} \\ & - 2.60 * \text{Female} - 3.16 * \text{African American} \\ & - 2.35 * \text{Hispanic} + 0.54 * {}_{\text{centered}}\text{Attendance Points} \\ & - 3.15 * \text{Attempted}_{5\text{-}28} + 0.38 * \text{Attempted}_{29\text{-}38} \\ & + 4.67 * \text{Attempted}_{39\text{-}40}\end{aligned} \tag{2}$$

The standardized coefficients, β, provided in Model 2 of Table 43 provide a measure of the relative impact of each significant predictor on a student's Percent Exam Points in general chemistry. According to this table, ReMATCH Attempted = 39 to 40 has the fourth largest impact of the predictor variables included in the model, behind ACT_{math}, HSGPA, and Attendance Points. Each of these three stronger predictors have over twice the standard impact of attempting 39-40 ReMATCH problems. When the unstandardized coefficients (B) are examined, it is clear that students who attempted 39-40 ReMATCH problems earned on average 4.7 exam points above what would have been expected of equivalent students in the comparison group. Students can earn a little over one-half of an exam point for attending class an additional day when attendance is checked, but for students who attend class the average amount, they can only earn a maximum of seven more attendance points, or roughly an additional 3.5 exam points. Also, students cannot alter their background (HSGPA or ACT_{math}) score once in the course; so, based on this MLR prediction model, students are left with attempting 39-40 ReMATCH problems as the most beneficial step they can take to improving their Percent Exam Points.

The histogram displaying the distribution of residuals shown in Figure 38 indicated that the MLR assumption of normally distributed residuals was met for this analysis. The close fit of the data to the diagonal line in the Normal P-P plot shown in Figure 39 confirmed that the residuals were fairly normally distributed, such that the predicted distribution produced by Equation 2 models the expected normal distribution very well. A scatterplot of residuals versus Percent Exam Points is shown in Figure 40. This plot illustrates that the MLR assumption of residual homoscedascity (or, the homogeneity of residual error assumption) was met for this analysis. The assumption of homoscedascity is satisfied when the variance of the residuals are roughly equal across the range of the dependent variable. Figure 40 shows that the residuals have a roughly equal spread of at each level of the Percent Exam Points.

Table 41

2006 Model Summary[c] Using Background Variables and $\text{Experimental}_{2006}$ as Predictors of Percent Exam Points

					Change Statistics					
Model	R	R^2	Adj. R^2	SE of the Estimate	R^2 Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	0.639[a]	.408	.403	9.67320	.408	80.142	6	698	.000	
2	0.639[b]	.409	.403	9.67236	.001	1.121	1	697	.290	2.001

a. Predictors: (Constant), $_{\text{centered}}$Attendance Points, African American, Female, Hispanic, $_{\text{centered}}\text{ACT}_{\text{math}}$, $_{\text{centered}}$HSGPA

b. Predictors: (Constant), $_{\text{centered}}$Attendance Points, African American, Female, Hispanic, $_{\text{centered}}\text{ACT}_{\text{math}}$, $_{\text{centered}}$HSGPA, $\text{Experimental}_{2006}$

c. Dependent Variable: Percent Exam Points

Table 42

2006 Model Summary[c] Using Background Variables and $\text{ReMATCH}_{\text{attempted}}$ Levels as Predictors of Percent Exam Points

					Change Statistics					
Model	R	R^2	Adj. R^2	SE of the Estimate	R^2 Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	0.639[a]	.408	.403	9.67320	.408	80.142	6	698	.000	
2	0.653[b]	.427	.419	9.53991	.019	7.547	3	695	.000	2.049

a. Predictors: (Constant), $_{\text{centered}}$Attendance Points, African American, Female, Hispanic, $_{\text{centered}}\text{ACT}_{\text{math}}$, $_{\text{centered}}$HSGPA

b. Predictors: (Constant), $_{\text{centered}}$Attendance Points, African American, Female, Hispanic, $_{\text{centered}}\text{ACT}_{\text{math}}$, $_{\text{centered}}$HSGPA, ReMATCH Attempted = 29 to 38, ReMATCH Attempted = 39 to 40, ReMATCH Attempted = 5 to 28

c. Dependent Variable: Percent Exam Points

Table 43

2006 Coefficients[a] – Used to Create Equation 2

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% CI for B	
		B	SE	β	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	73.137	.549		133.29	.000	72.060	74.215
	$_{centered}$HSGPA	9.045	1.117	.284	8.10	.000	6.852	11.239
	$_{centered}ACT_{math}$	.936	.110	.292	8.48	.000	.719	1.153
	Female	-2.570	.805	-.103	-3.19	.001	-4.150	-.991
	African American	-3.287	1.778	-.055	-1.85	.065	-6.778	.203
	Hispanic	-2.652	1.964	-.040	-1.35	.177	-6.508	1.204
	$_{centered}$Attendance Points	.582	.064	.278	9.07	.000	.456	.708
2	(Constant)	72.984	.590		123.75	.000	71.826	74.142
	$_{centered}$HSGPA	8.359	1.112	.262	7.52	.000	6.177	10.542
	$_{centered}ACT_{math}$	.907	.109	.283	8.31	.000	.693	1.121
	Female	-2.603	.794	-.104	-3.28	.001	-4.161	-1.045
	African American	-3.164	1.755	-.053	-1.80	.072	-6.610	.282
	Hispanic	-2.346	1.940	-.035	-1.21	.227	-6.154	1.463
	$_{centered}$Attendance Points	.541	.064	.259	8.46	.000	.416	.667
	ReMATCH Attempted = 5 to 28	-3.154	1.293	-.072	-2.44	.015	-5.693	-.614
	ReMATCH Attempted = 29 to 38	.377	1.323	.008	0.29	.776	-2.220	2.974
	ReMATCH Attempted = 39 to 40	4.674	1.207	.115	3.87	.000	2.304	7.044

a. Dependent Variable: Percent Exam Points

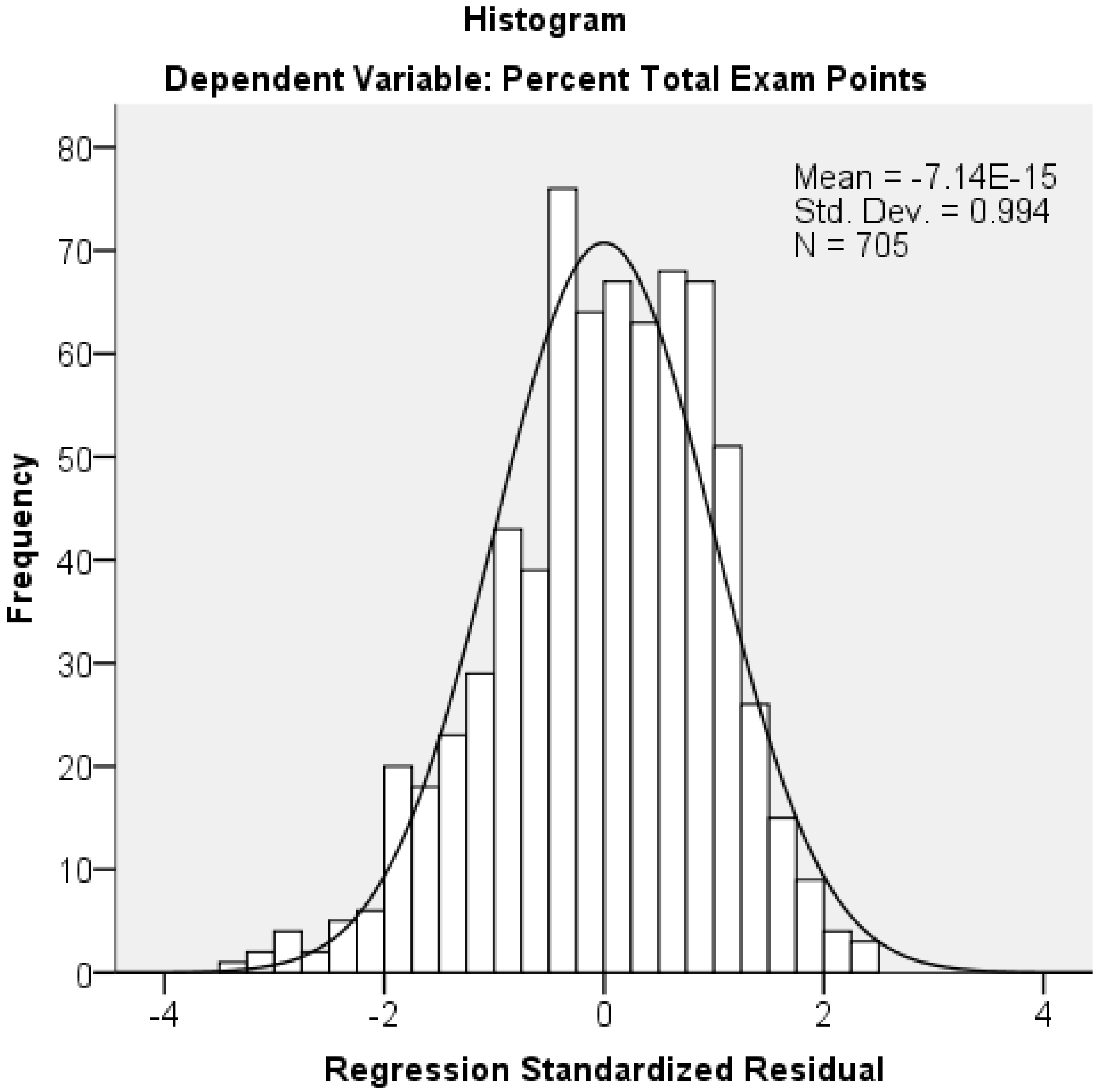


Figure 38 Displays a histogram illustrating the normally distributed residuals resulting from the MLR analysis using background variables and ReMATCH$_{attempted}$ levels (described in Table 42 and Equation 2) to predicted Percent Exam Points in 2006. The residual values were obtained by subtracting Percent Exam Points Observed from Predicted Percent Exam Points.

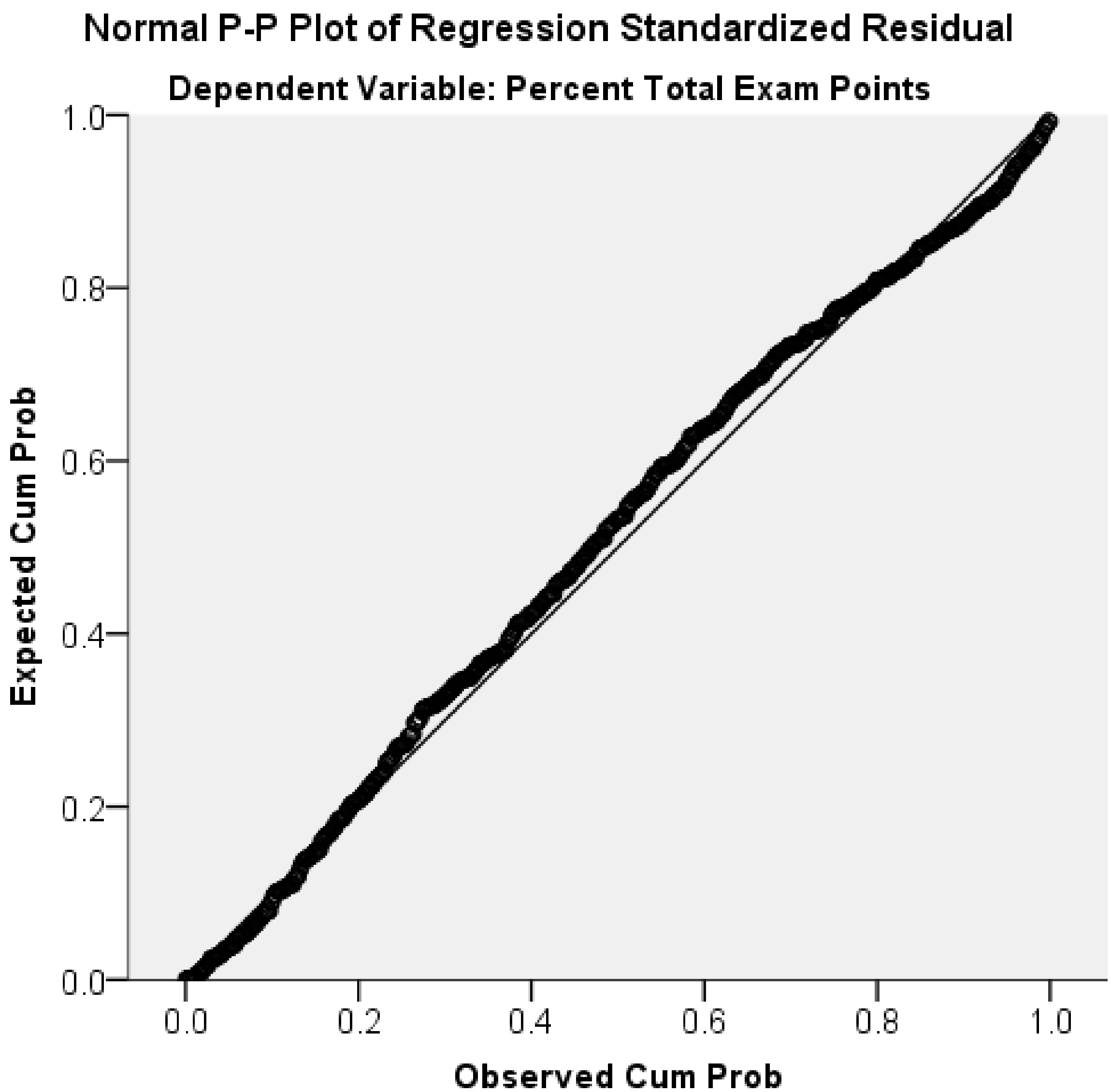


Figure 39The close fit of the data to the diagonal line in this normal P-P plot confirmed that the residuals for 2006 were well modeled by a normal curve. The diagonal line represents the relationship that would be expected if the predicted distribution was perfectly normal. Small deviations from this diagonal are acceptable. Therefore, the predicted distribution produced by Equation 2 models the expected normal distribution for Percent Exam Points very well.

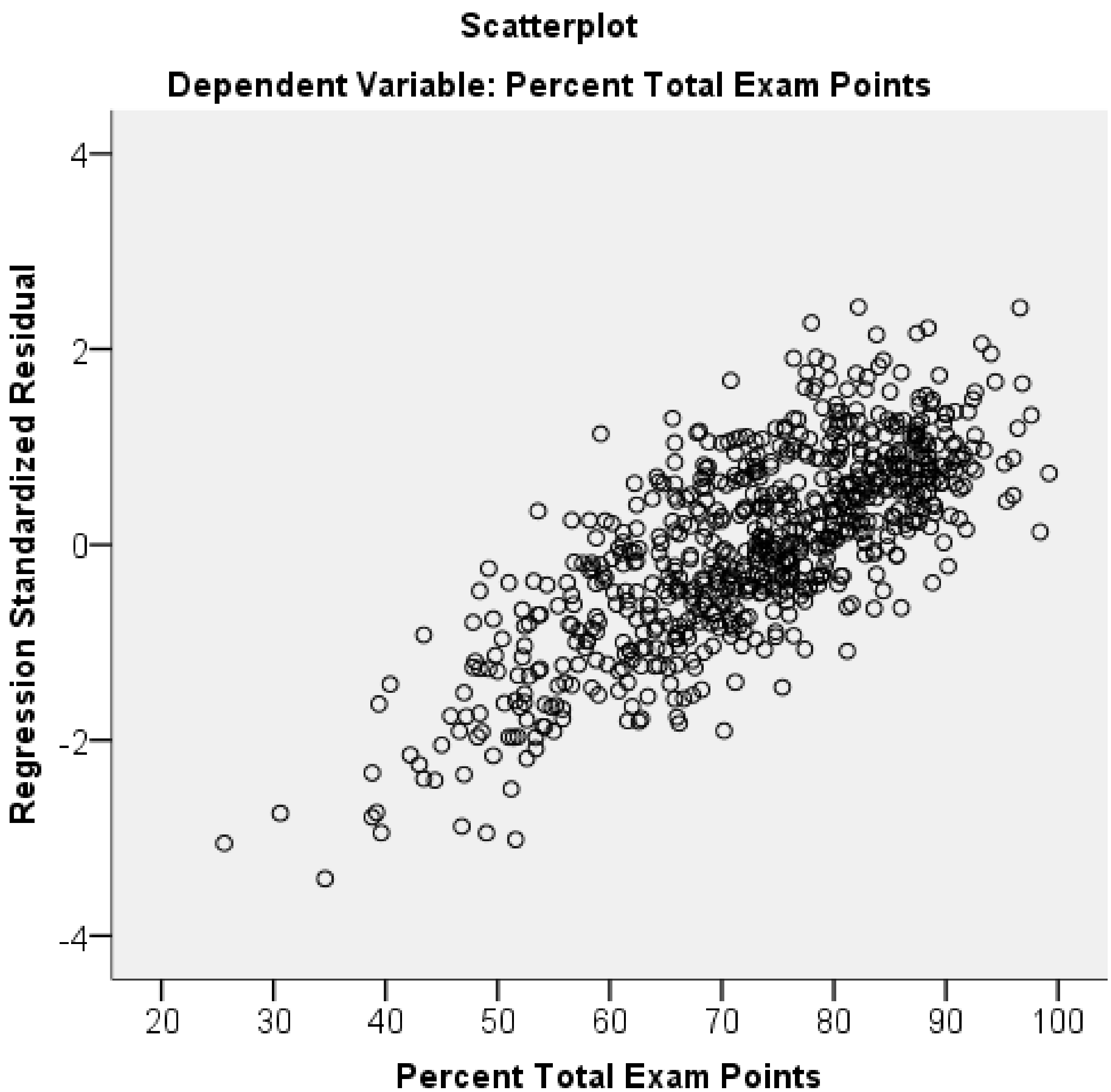


Figure 40Displays a scatterplot of residuals versus Percent Exam Points for 2006. This plot illustrates that the MLR assumption of residual homoscedascity was met for this model of Percent Exam Points based on student background variables and the students level of ReMATCH use, as measured by their $\text{ReMATCH}_{\text{attempted}}$ level. The assumption of homoscedascity is satisfied when the variance of the residuals are roughly equal across the range of the dependent variable. This figures shows that the residuals have a roughly equal spread of at each level of the predicted Percent Exam Points.

Correlations Between Background Variables and Percent Exam Points for 2007

Bivariate correlation coefficients for background and attendance variables with Percent Exam Points (Table 44) show that HSGPA and ACT_{math} are background variables with two of the strongest relationships to Percent Exam Points. Of the other 25 variables, 14 were significantly correlated with Percent Exam Points in these bivariate correlations. However, an examination of the partial correlation coefficients shows that only five of these variables – (1) Female, (2) Asian, (3) Hispanic, (4) $Math_{college}$ = Calculus I, and (5) Attendance Points – were significantly correlated with the criterion once the effects of HSGPA and ACT_{math} were held constant. This supports the idea that HSGPA and/or ACT_{math} acted as mediators of the bivariate relationships between Percent Exam Points and the other 9 background variables in 2007 that were no longer significant predictors in the partial correlations. Table 45 shows that several significant relationships were present in the bivariate correlations among HSGPA and ACT_{math} and the five variables that were significantly correlated with Percent Exam Points in the partial correlations. However, none of these correlation coefficients were greater than $r = .50$, so none of these variables were likely to be redundant or cause multicollinearity concerns in the MLR analysis. Therefore, seven variables were included in the first step of the MLR analysis for 2007.

Table 44

2007 Bivariate Correlations Between Percent Exam Points and Background Data and Related Partial Correlations Controlling for HSGPA and ACT_{math}

		Bivariate Correlation (unless noted, n = 668)	**Partial Correlation** (n = 601)
Independent Variables		**Dependent Variable** Percent Exam Points	Percent Exam Points
HSGPA	r	.420**	Effects Partialed Out
(n = 621)	p	.000	
ACT_{math}	r	.510**	Effects Partialed Out
(n = 613)	p	.000	
$ACT_{composite}$	r	.450**	.052
(n = 613)	p	.000	.204
Female	r	-.079*	-.082*
	p	.040	.045
African American	r	-.037	.019
	p	.338	.641
Asian	r	.044	.102*
	p	.251	.012
Hispanic	r	-.114**	-.097*
	p	.003	.017
Caucasian	r	.005	-.047
	p	.892	.253
Other Ethnicity	r	.045	.031
	p	.243	.449
$Level_{enrolled}$ = Fresh.	r	.067	-.018
	p	.085	.657
$Level_{enrolled}$ = Soph.	r	-.062	.027
	p	.109	.507
$Level_{enrolled}$ = Junior	r	.002	-.001
	p	.950	.987
$Level_{enrolled}$ = Senior	r	-.042	-.019
	p	.284	.640

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 44 - continued

2007 Bivariate Correlations Between Percent Exam Points and Background Data and Related Partial Correlations Controlling for HSGPA and ACT_{math} (continued)

		Bivariate Correlation (unless noted, n = 668)	Partial Correlation (df = 601)
Independent Variables		**Dependent Variable**	
		Percent Exam Points	Percent Exam Points
$Status_{entry}$ = Freshman	r	.147**	.063
	p	.000	.123
$Status_{entry}$ = Transfer	r	-.124**	-.050
	p	.001	.219
$Status_{entry}$ = Other	r	-.073	-.036
	p	.058	.377
$\Delta Time_{matric}$ (years)	r	-.095*	.053
	p	.014	.194
$Math_{college}$ = None	r	.092*	-.044
	p	.018	.276
$Math_{college}$= ColAlg/Trig/PreCalc	r	-.262**	-.078
	p	.000	.055
$Math_{college}$ = Calc I	r	.050	.109**
	p	.194	.007
$Math_{college}$ = Calc II and Above	r	.168**	.026
	p	.000	.526
$Status_{enrolled}$ = First Sem. Freshman	r	.174**	-.023
	p	.000	.577
$Status_{enrolled}$ = First Sem. Transfer	r	-.081*	-.072
	p	.037	.076
$Status_{enrolled}$ = Prior Freshman	r	-.124**	.066
	p	.001	.103
$Status_{enrolled}$ = Prior Sophomore	r	-.087*	.021
	p	.024	.614
$Status_{enrolled}$ = Prior Jr. or Sr.	r	-.014	-.007
	p	.718	.872
Attendance Points	r	.337**	.300**
	p	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 45

2007 Correlations[a] Between Possible Predictor Variables for MLR Analysis

		HSGPA	ACT_{math}	Female	Asian	Hispanic	$Math_{college}$ = Calculus I	Attendance Points
HSGPA	*r*	1	.440**	.262**	-.013	-.024	-.019	.317**
	p		.000	.000	.753	.559	.646	.000
ACT_{math}	*r*		1	-.124**	-.036	-.046	-.060	.085*
	p			.002	.372	.256	.142	.037
Female	*r*			1	.081*	-.031	.045	.131**
	p				.047	.453	.271	.001
Asian	*r*				1	-.045	.089*	-.004
	p					.266	.028	.923
Hispanic	*r*					1	-.040	-.106**
	p						.325	.009
$Math_{college}$ = Calculus I	*r*						1	-.110**
	p							.007
Attendance Points	*r*							1
	p							

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. Listwise *n* = 605

MLR Analysis for Effect of Background, Attendance, and Tutorial-Use on Percent Exam Points for 2007

A multiple linear regression analysis was conducted to predict the Percent Exam Points from demographic and academic background variables and Percent Attendance Points. The results of this analysis indicated that these predictor variables accounted for a significant amount (nearly 40%) of the Percent Exam Points students earned, $R^2 = .40$ (adj. $R^2 = .39$), $F\ (7, 597) = 55.63$, $p < .001$ (Model 1, Table 46). The coefficients from this analysis (Model 1, Table 47) indicated that, generally,

(1) students with higher HSGPA, ACT_{math}, and Percent Attendance Points values earned higher values for Percent Exam Points,

(2) female students performed slightly more poorly than their male classmates with equivalent values for HSGPA, ACT_{math} and Percent Attendance Points,

(3) Asian students performed slightly better than their classmates of other ethnicities with equivalent values for HSGPA and ACT_{math}, and

(4) students whose last college-level math course was Calculus I performed slightly better than their classmates from other prior college-level math courses or no college math courses.

The coefficient for the Hispanic variable was not significant in this model.

A second analysis was conducted to evaluate whether the level of tutorial use, as measured by membership in the upper and lower levels of $\text{ReMATCH}_{attempted}$ and Content Pages_{viewed}, variables, predicted Percent Exam Points above and beyond that predicted by the background and attendance variables alone. Previously reported correlations between $\text{ReMATCH}_{attempted}$ and Content Pages_{viewed} demonstrated that these variables only share a small significant correlation and, thus, can appear in the same MLR analysis. With these four dichotomous measures representing the students' levels of tutorial use, the new model accounted for a significant proportion (over 45%) of the Percent Exam Points after controlling for the effects of background and course attendance, R^2 change = .45 (adj. R^2 change = .44), $F\ (4, 593) = 15.49$, $p < .001$ (Model 2,Table 46). The coefficients from this analysis (Model 2, Table 47) indicated that for students in 2007 with similar background and attendance values, generally,

(1) those who attempted 39-40 ReMATCH problems earned higher Percent Exam Points values than similar students who did not,

(2) those who attempted only 5-28 ReMATCH problems earned lower Percent Exam Points values than similar students who attempted more, and

(3) those who viewed at least half of the tutorial content pages earned higher Percent Exam Points values than similar students who viewed fewer content pages.

The non-significant coefficient for students who viewed the lowest number of ReMATCH content pages indicated that these students did not differ from their equivalent counterparts who viewed more content pages. Using the coefficients from this final model in Table 47, the MLR equation for Predicted Percent Exam Points based on the 2007 data is provided as Equation 3.

$$\begin{aligned}\text{2007 Predicted} & \\ \text{Percent Exam Points} = {} & 65.14 + 4.75 * {}_{\text{centered}}\text{HSGPA} + 1.16 * {}_{\text{centered}}\text{ACT}_{\text{math}} \\ & - 2.60 * \text{Female} - 3.66 * \text{Asian} \\ & - 2.48 * \text{Hispanic} + 3.60 * \text{Calculus I} \\ & + 0.58 * {}_{\text{centered}}\text{Attendance Points} \\ & - 4.07 * \text{Attempted}_{5\text{-}28} + 6.54 * \text{Attempted}_{39\text{-}40} \\ & + .67 * \text{Content Pages}_{0\text{-}10} + 1.90 * \text{Content Pages}_{44\text{-}88}.\end{aligned} \tag{3}$$

The standardized coefficients, β, shown in Model 3 of Table 47 provide a measure of the relative impact of each significant predictor on a student's Percent Exam Points in general chemistry in 2007. According to this table, ReMATCH Attempted = 39 to 40 has the third largest impact of the predictor variables in this model, behind ACT_{math} and Attendance Points. ACT_{math} has nearly double the standard impact of attempting 39-40 ReMATCH problems, but Attendance Points has a nearly equivalent impact. In this comparison, the standardized impact of viewing 44+ content pages is very small, only one-third the size of Attempted 39-40. When the unstandardized coefficients (B) are examined, it is clear that students who attempted 39-40 ReMATCH problems earned on average 6.5

exam points above the predicted score of an equivalent students who only Attempted 29-38 ReMATCH problems. Those students who viewed 44+ pages are shown to earn nearly 2 Percent Exam Points above their predicted score. Students can earn nearly six-tenths of an exam point for attending class an additional day when attendance is checked. However, for students who attend class the average amount, they can only earn a maximum of eight more attendance points (an additional 4.6 exam points). Students cannot change their background (Ethnicity, HSGPA, or ACT_{math} score) once in the course; so, based on this MLR prediction mode for 2007, students are left with attempting 39-40 ReMATCH problems or viewing 44+ tutorial pages, preferably both, as the most beneficial step they can take to improve their Percent Exam Points. Combined these are predicted to provide an additional 8.5 Percent Exam Points.

Table 46

2007 Model Summary[c] Using Background Variables and $ReMATCH_{attempted}$ Levels and Content Pages Viewed Levels as Predictors of Percent Exam Points

					Change Statistics					
Model	R	R^2	Adj. R^2	SE of the Estimate	R^2 Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.628	.395	.388	9.77786	.395	55.626	7	597	.000	
2	.672	.452	.442	9.33521	.057	15.490	4	593	.000	2.143

a. Predictors: (Constant), $_{centered}$Attendance Points, Asian, Female, Hispanic, $_{centered}ACT_{math}$, $_{centered}$HSGPA, $Math_{college}$ = Calculus I
b. Predictors: (Constant), $_{centered}$Attendance Points, African American, Female, Hispanic, $_{centered}ACT_{math}$, $_{centered}$HSGPA, $Math_{college}$ = Calculus I, ReMATCH Attempted = 39 to 40, ReMATCH Attempted = 5 to 28, ReMATCH Pages Viewed = 0 to 10, ReMATCH Pages Viewed = 44 to 88
c. Dependent Variable: Percent Exam Points

The histogram displaying the distribution of residuals shown in Figure 41 indicated that the MLR assumption of normally distributed residuals was met for this analysis. The exceptionally close fit of the data to the diagonal line in the Normal P-P plot shown in Figure 42 confirmed that the residuals were normally distributed, such that the predicted distribution produced by Equation 3 models the expected normal distribution very well. A scatterplot of residuals versus Percent Exam Points is shown in Figure 43. This plot illustrates that the MLR assumption of residual homoscedascity (or, the homogeneity of residual error assumption) was met for this analysis. The assumption of homoscedascity is satisfied when the variance of the residuals is roughly equal across the range of the dependent variable. Figure 43 shows that the residuals had a roughly equal spread at each level of the Percent Exam Points.

Table 47

2007 Coefficients[a] – Used to Create Equation 3

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% CI for B	
		B	SE	β	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	70.688	.611		115.70	.000	69.488	71.887
	$_{centered}$HSGPA	5.463	1.239	.175	4.41	.000	3.029	7.896
	$_{centered}$ACT$_{math}$	1.243	.115	.402	10.85	.000	1.018	1.468
	Female	-2.430	.862	-.097	-2.82	.005	-4.124	-.737
	Asian	4.172	1.652	.081	2.52	.012	.927	7.417
	Hispanic	-3.509	2.363	-.048	-1.49	.138	-8.149	1.131
	Math$_{college}$ = Calculus I	3.589	1.002	.116	3.58	.000	1.622	5.557
	$_{centered}$Attendance Points	.767	.094	.278	8.14	.000	.582	.952
2	(Constant)	65.142	1.278		50.97	.000	62.632	67.652
	$_{centered}$HSGPA	4.753	1.191	.152	3.99	.000	2.414	7.092
	$_{centered}$ACT$_{math}$	1.165	.110	.377	10.57	.000	.949	1.382
	Female	-2.596	.830	-.104	-3.13	.002	-4.227	-.966
	Asian	3.660	1.589	.071	2.30	.022	.540	6.780
	Hispanic	-2.478	2.263	-.034	-1.10	.274	-6.923	1.966
	Math$_{college}$ = Calculus I	3.600	.969	.116	3.72	.000	1.697	5.503
	$_{centered}$Attendance Points	.580	.094	.210	6.19	.000	.396	.763
	ReMATCH Attempted = 5 to 28	-4.067	1.974	-.077	-2.06	.040	-7.944	-.189
	ReMATCH Attempted = 39 to 40	6.538	1.277	.195	5.12	.000	4.031	9.046
	ReMATCH Pages Viewed = 0 to 10	.666	.963	.023	0.69	.489	-1.224	2.557
	ReMATCH Pages Viewed = 44 to 88	1.901	.946	.065	2.01	.045	.042	3.759

a. Dependent Variable: Percent Exam Points

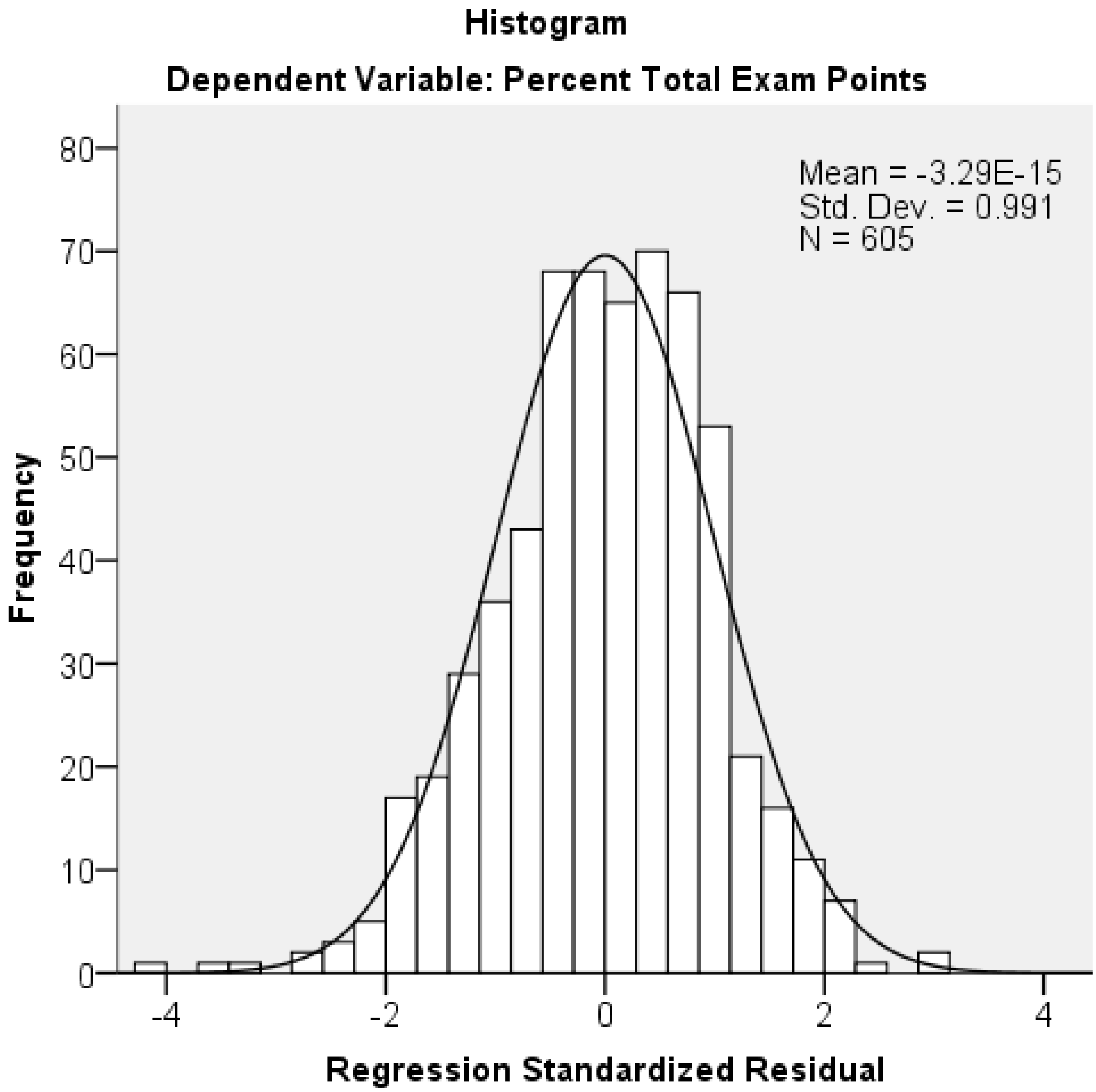


Figure 41Displays a histogram illustrating the normally distributed residuals resulting from the MLR analysis using background variables and $\text{ReMATCH}_{\text{attempted}}$ and Content Pages Viewed levels (described in Table 42 and Equation 3) to predicted Percent Exam Points in 2007. The residual values were obtained by subtracting Percent Exam Points Observed from Predicted Percent Exam Points.

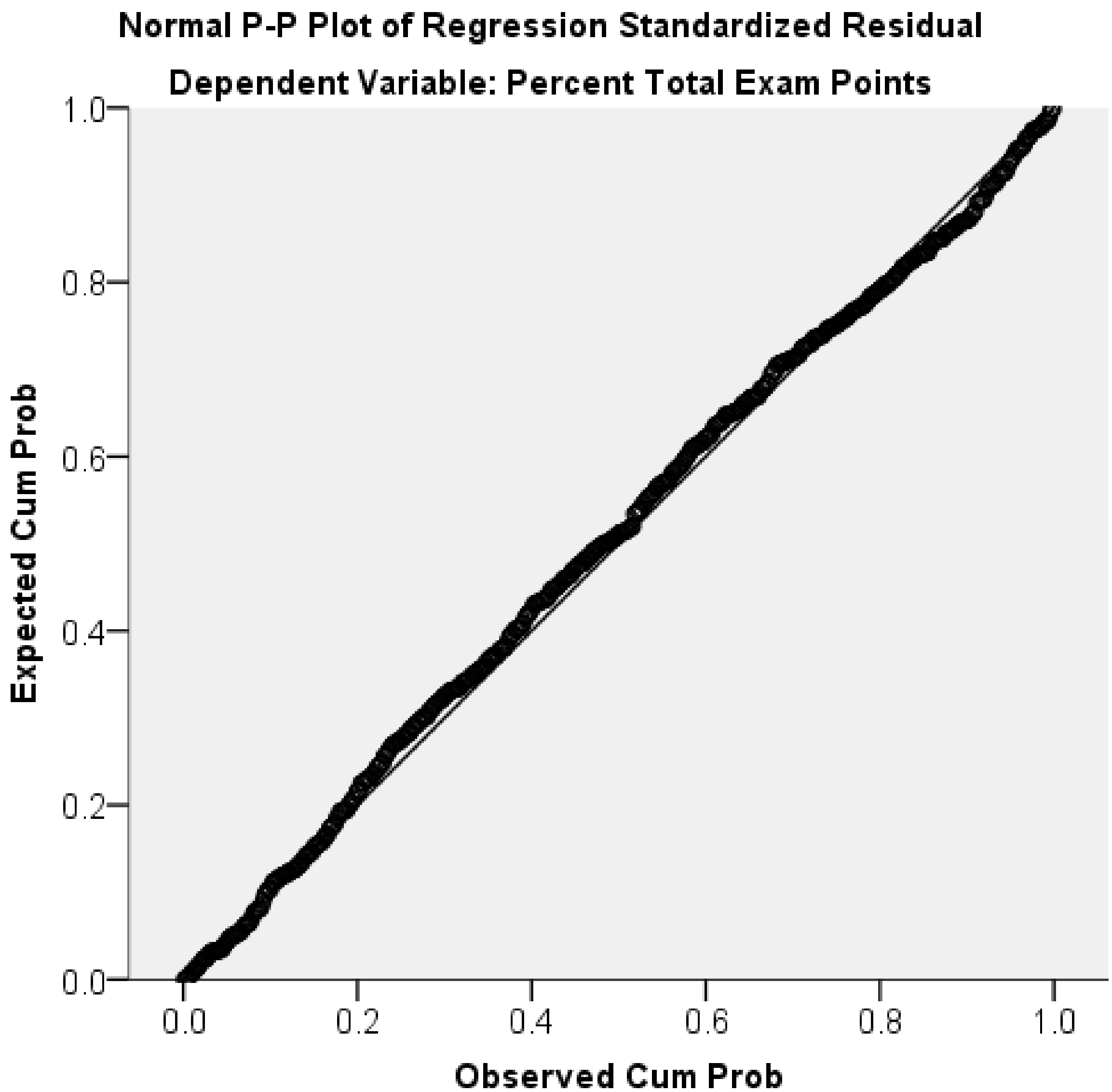


Figure 42Displays a Normal P-P plot illustrating the close fit of the data to the diagonal line which represents a normal distribution in this plot. Therefore, when observed values are close to the diagonal line the normality of the residuals for the model is confirmed. This plot shows that the 2007 residuals were exceptionally well fit to the normal curve. Therefore, the predicted distribution produced by Equation 3 models the expected normal distribution for Percent Exam Points very well.

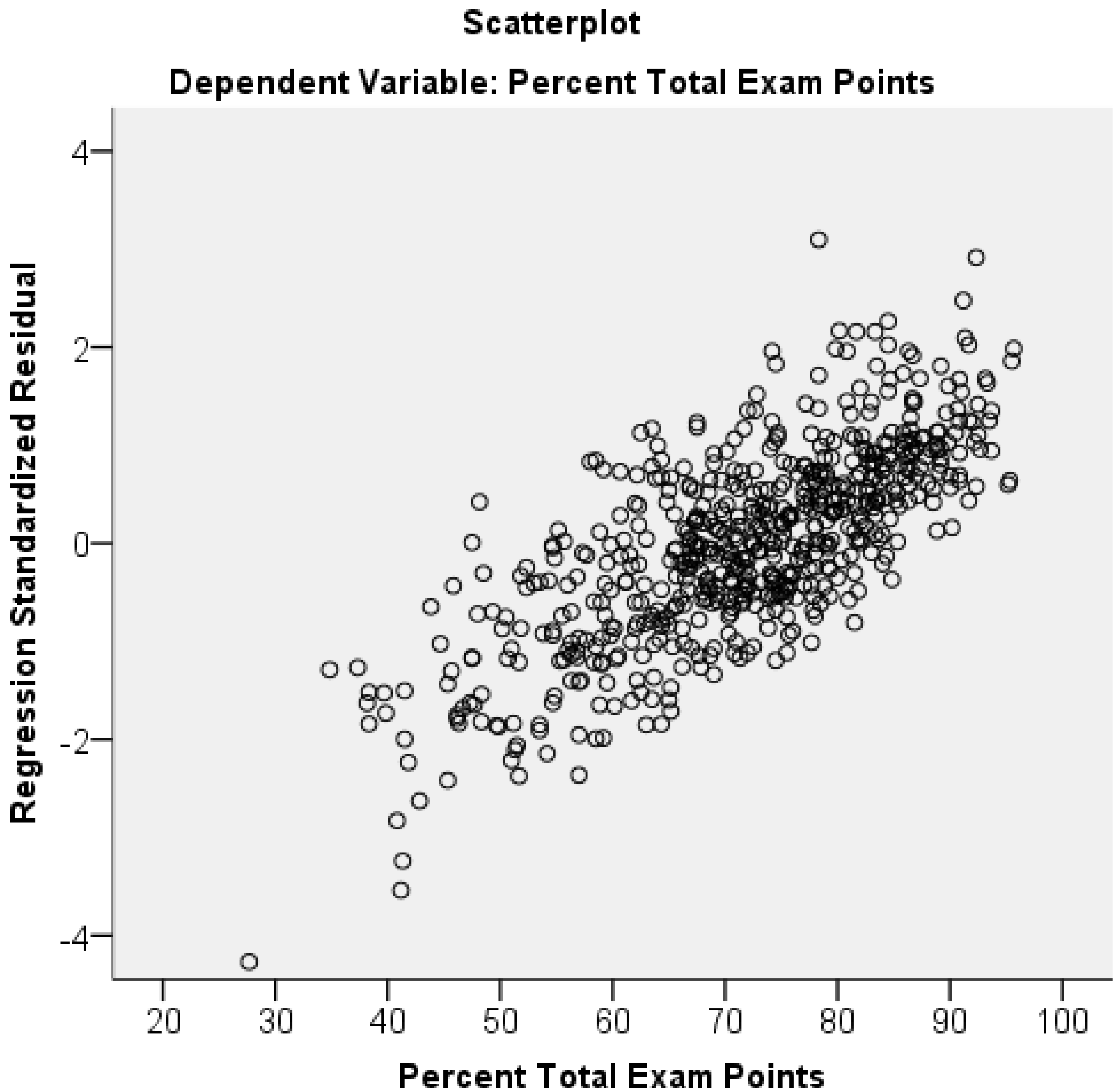


Figure 43Displays a scatterplot of residuals versus Percent Exam Points for 2007. This plot illustrates that the MLR assumption of residual homoscedascity was met for this model of Percent Exam Points based on student background variables and the students level of ReMATCH use, as measured by both their $\text{ReMATCH}_{\text{attempted}}$ and Content Pages Viewed level. The assumption of homoscedascity is satisfied when the variance of the residuals is nearly equal across the range of the dependent variable. This figures shows that the residuals have a relatively equal spread of at each level of the predicted Percent Exam Points. The one lone point is not of concern because it follows the diagonally rectangular trend of other points but is simply reported for a much lower Percent Exam Points score. The slightly high point is not concerning because it is still below the typical limit for consideration of an outlier (±3 SD).

Discussion of MLR Analysis Relating Background and Tutorial Use to Course Performance

Bivariate correlations comparing multiple background variables with Percent Exam Points conducted in preparation for the MLR Analyses, indicated significant correlations between Percent Exam Points and many background variables. Once HSGPA & ACT_{math} were controlled, most of the previously significant bivariate correlations between background variables and Percent Exam Points became non-significant partial correlations. Exceptions to this trend were the gender and several of the ethnicity categories. Being female, African American, or Hispanic was associated with lower Percent Exam Points, while being Asian was associated with higher Percent Exam Points. When these demographic variables were incorporated into the MLR analyses, only being Female (for 2006 and 2007) or Asian (for 2007) continued to exert their significance on Percent Exam Points. In the MLR analyses, HSGPA, ACT_{math}, and Attendance Points continued to be some of the most significant predictors of student performance on exams in general chemistry at KU.

Adding ReMATCH-use variables to the MLR model that already included background (ACT_{math}, HSGPA, Female, Minorities) and attendance variables to predict Percent Exam Points resulted in a significant increase in the amount of variance associated in Percent Exam Points that the new the model explained. Model 2 for 2006 and 2007 accounted for 42% and 45% of variance in Percent Exam Points, respectively. In Model 2 for both years, ACT_{math} was the largest contributing predictor. In 2006, students attempting 39-40 ReMATCH problems were predicted to earn nearly 5 Percent Exam Points more than equivalent students in the comparison group. Considering that moving up one letter grade in 2006 was associated with an increase of 8-13 Percent Exam Points, students in the experimental group who attempted 39-40 ReMATCH homework problems were predicted to see an increase of four-tenths to six-tenths of one letter grade. This is enough of a change to progress from a C+ (2.3) to a B- (2.7) or nearly to a B (3.0).

The scenario modeled in 2007 is considerably different from that in 2006 because the 2007 study lacked a true comparison group. Therefore, subsets of ReMATCH users were selected to serve as the reference group for the model. In 2007, the reference groups were ReMATCH users who attempted

29-38 problems and ReMATCH users who viewed 11-43 ReMATCH content pages. This reference group does not necessarily represent the best students in the general chemistry course since the group is defined by the fact that its members only completed 72% – 95% of their ReMATCH assignments. However, by comparison to students with lower completion rates, this group also does not represent the poorest performing students; and, thus, provides a suitable reference group in the 2007. Difference in Percent Exam Points between letter grades in 2007 ranged from 6-12 Percent Exam Points. According to the coefficients in Model 2 for 2007, students attempting 39-40 ReMATCH problems and viewing 44+ Content Pages was predicted to earn an additional 8.5 Percent Exam Points above that predicted for equivalent students who attempted only 29-38 ReMATCH problems and viewed fewer than 44 Content Pages. In 2007, an additional 8.5 Percent Exam Points constitutes somewhere between a seven-tenths and a fourteen-tenths (140%) improvement in letter grade. This is enough of a change to progress from a C+ (2.3) to a B (3.0) or to an A- (3.7).

The standardized coefficients for the ReMATCH-use variables may make their impact on student course performance, as measured by Percent Exam Points, appear small compared to the impacts of ACT_{math}, HSGPA, and Attendance Points. However, the impact of students using the tutorial as it was designed to be used (attempting 39-40 problems and viewing at least half of the tutorial pages) is predicted to be a significant one on students' Percent Exam Points. Examining how this significant increase in Percent Exam Points impacts a students' overall letter grade for the course highlights the degree to which the student benefits from attempting all of the ReMATCH homework problems in the studies from both years. Graphical methods to check normality and homoscedacity of the residuals from both final MLR models demonstrated that the data originated from appropriate samples for this type of analysis. From the results of these analyses, the suggestion that ReMATCH use has an impact on a student's overall Percent Exam Points is strengthened. The 2006 model provides evidence supporting the hypothesis that working on the ReMATCH homework problems, one measure of ReMATCH use, is predicted to improve a student's exam performance. Additionally, the 2007 model supports the hypothesis that visits to the ReMATCH tutorial pages (another measure of ReMATCH use) are also predicted to improve a student's exam performance.

Chapter 8

Results of Survey Responses

The survey response rates for students with scores for each exam differed between the initial and final surveys and between years. Students in the sample accepted the informed consent statements as part of the initial survey for the 2006 study and as part of both the initial and final surveys for the 2007 study. Consequently, in 2006, all of the students who agreed to be in the sample responded to the initial survey. Of these, over 87% subsequently completed the final survey. In 2007, just over 67% responded to the initial survey, but nearly 95% of the students responded to the final survey. As a result, just over 62% of the students had responses to both surveys.

Summary of Responses to Demographic and Academic Background Questions on the Surveys

According to student responses to initial survey questions regarding their demographic backgrounds in 2006 and 2007, 53-58% of the students in each of the *groups of interest* were 18 years old at the beginning of the course, 32-36% were 19 or 20 years old, and the other, roughly, 10% were 21 or older. Ethnicities, as self-reported by students, matched the University data for over 93% of the students in both years of the study, while student-reported gender matched that recorded with the University over 99% of the time. Based on the high degree of agreement between student responses on the initial survey and the University data, it appears that students were answering the initial survey questions honestly.

Both the initial and final surveys for each year requested students to indicate their major(s). Collecting this data provided a more complete description of the students enrolled in the general chemistry course to assist other researchers in determining the generalizability of these studies to other institutions. Table 48 displays a summary of the majors that students indicated on both surveys. The total of each column in Table 48 is greater than 100% because students were given the option of choosing multiple majors. Across both surveys and both years, 1-3% of students marked chemistry as their major, an additional 7-8% marked chemical engineering, and another 2-4% marked biochemistry. Other engineering majors made up another 11-14% of the students initially. Biology majors composed the largest portion of students in both years, between 21-30%. Pre-medicine and pre-pharmacy, while not majors, were included on this list because many University students wanting to attend medical or pharmacy school identify more with these designations than with any specific major. These choices reflect 16-22% (pre-medicine) and 13-14% (pre-pharmacy) of the students. The pre-medicine and pre-pharmacy designations were also the ones that saw the largest decrease in the portion of students selecting these on the final survey. Across both years, 5-8% removed the pre-medicine designation and 2-4% removed the pre-pharmacy designation. In the 2007 study, when the "undecided" option appeared, 7-8% of the sample chose this option.

Students also provided information about their high school math and science coursework on the initial surveys for both years (Table 49). According to survey responses from 2006, 72% of the students took a pre-calculus course in high school and 48% took a calculus course in high school. In 2007, these values rose: 77% indicated that they took a pre-calculus course in high school and 54% indicated that they took a calculus course in high school. For both years, over 95% reported that they took a chemistry course in high school, while around 75% took a physics course in high school.

Comfort with Math-Related Chemistry Topics – Survey Questions

ReMATCH was designed to increase student confidence with solving math-related chemistry problems in addition to teaching students the necessary facts, skills, and metacognitive processes to successfully solve such problems. Significant portions of the general chemistry students from the preliminary study in 2005 reported struggling near the end of the semester with at least some of the introductory math-related chemistry topics. Based on these findings, it was determined that the analysis

Table 48

Percent of Students Pursuing Different Majors for Both Years

Majors	2006 Initial Survey % (n = 766)	2006 Final Survey % (n = 673)	2007 Initial Survey % (n = 450)	2007 Final Survey % (n = 633)
Biochemistry	3.4	3.7	1.6	2.8
Biology	29.6	30.3	21.1	23.5
Chemical or Petroleum Engineering	6.9	6.5	6.9	8.4
Chemistry	3.0	3.3	1.1	1.7
Business	1.8	4.6	2.4	4.7
Architecture	1.7	0.6	2.9	3.0
Engineering, other	11.4	11.9	13.6	16.9
Science, other	8.6	11.0	10.0	12.5
Foreign Language	2.5	3.1	0.9	1.6
Humanities or Arts	3.1	3.3	2.9	6.2
Social Sciences	6.0	7.4	7.1	6.6
Mathematics	0.5	1.6	0.2	0
Nursing	3.7	4.8	2.4	3.2
Pre-Pharmacy	14.4	12.5	12.7	9.0
Physics	2.4	2.1	1.8	1.7
Pre-Medicine	21.9	17.2	16.4	8.2
Teaching, any	0.9	1.9	0.4	0.5
Other, not listed major	5.9	4.5	2.9	2.4
Undecided (2007 only)	--	--	7.3	8.4

Table 49

Percent of Students Previously Completing Each Course

High School Courses Taken	2006 Comparison % (n = 547)	2006 Experimental % (n = 219)	2007 % (n = 450)
Pre-Calculus	72.2	71.2	77.8
Calculus	47.5	48.4	54.5
Chemistry	96.2	96.8	95.3
Physics	74.2	74.4	76.3

of ReMATCH for both years needed to include components that examined whether student confidence with the math-related topics changed over the semester and whether any of that change was attributable to a student's use of ReMATCH. To accomplish this, questions regarding student confidence with these topics were included in the initial and final surveys for both years.

A conscious decision was made in forming these survey questions regarding student confidence not to ask the students specifically if they felt *confident* about their ability to apply this knowledge. For example, students could agree to a statement asking if *they feel confident in their ability to apply chemistry knowledge* but really mean that they feel confident that they will apply it incorrectly due to the ambiguity of the term. Additionally, confidence has a much more analytical connotation; and, there was a concern that students would only associate the term confidence with quantitative problem-solving aspects of the chemistry topic. That connotation of confidence was not the goal for this survey. This portion of the study was *less* interested in whether students felt they could always apply the chemistry topics perfectly; and was *more* interested in whether students felt comfortable with the topics and were willing to work with them to deepen their understanding of each topic. Consequently, the term *comfort* was selected over *confidence* when deciding how to proceed.

On the initial and final surveys for both years, students were asked to respond to the following statements, "Prior to this course, I felt comfortable with [topic]" or "Currently, I feel comfortable with [topic]," respectively, regarding the following math-related chemistry topics:

(1) the concept of the mole in chemistry,

(2) using significant figures,

(3) using scientific notation,

(4) applying rounding rules,

(5) converting between metric units,

(6) converting between grams and moles (2006 only),

(7) the concept of limiting reactants,

(8) the concept of theoretical yield, and

(9) the concept of molarity.

These questions were included to gauge student confidence with these math-related chemistry topics. Students responded to these questions on a 5-point Likert-style scale:

1 = Strongly Disagree,

2 = Inclined to Disagree,

3 = Neutral,

4 = Inclined to Agree, and

5 = Strongly Agree.

Students could also mark a sixth option, "I do not remember this topic," which was assigned a value of zero for the purpose of analysis. Table 50 provides the percent of students in each group of interest from 2006 and 2007 who marked on either survey that they did not remember a topic. On the initial surveys, 98% of the students in each group of interest remembered the topics of significant figures, scientific notation, rounding rules, and metric units. Not surprisingly, on the initial 2006 survey, the portion of students marking that they did not remember converting grams to moles was similar to the portion of students who did not remember the concept of the mole, roughly 10% in each case. The portion of students who did not remember the concept of the mole was lower in 2007, roughly 3%. Larger portions of students marked that they did not remember the topics of limiting reactants (17-31%), theoretical yield (24-36%), and molarity (12-24%).

Description of Student Comfort with Math-Related Chemistry Topics in 2006
– A Measure of Confidence

Table 51 displays the means and standard deviations from the 2006 study for both the comparison group and the experimental group, as well as for two subsets of the experimental group: (1) students attempting at least half of the ReMATCH homework problems, denoted as *20+*, and (2) students using the tutorial as it was designed to be used, denoted by 39+. ANOVAs for each topic comparing the 2006 comparison group to the 2006 experimental group, and each of these sub-groups, will be discussed in the next chapter, but the results of the analyses are also reported on Table 51. The

Table 50

Percent of Students in the 2006 Comparison and 2006 and 2007 Experimental (20+) Groups Marking the "I Do Not Remember This Topic" Option on Each Survey

I feel comfortable with …	Survey Instance	2006 Comp. %	2006 Exp. (20+) %	2007 Exp. (20+) %
the concept of the mole.	initial	10.1	9.1	3.2
	final	0.2	0.5	0.3
using significant figures.	initial	1.3	2.3	2.3
	final	0	0	0.3
using scientific notation.	initial	0.7	0.5	0.5
	final	0	0	0.3
applying rounding rules.	initial	0.7	0.9	0.7
	final	0.2	0.5	0.3
converting between metric units.	initial	0.7	0.9	0.5
	final	0.6	0	0.3
converting between grams and moles.	initial	10.1	8.7	--
	final	0.2	0	--
the concept of limiting reactants.	initial	31.4	30.1	17.2
	final	1.5	1.0	0.6
the concept of theoretical yield.	initial	36.0	33.8	24.3
	final	6.0	2.6	0.3
the concept of molarity.	initial	23.8	17.8	11.7
	final	1.0	0	0.2

full experimental group and the 20+ subset of the experimental group were shown not to differ significantly from the comparison group in regards to

(1) HSGPA (Full experimental, t (727) = .174, p = .862)
(ReMATCH$_{attempted}$ = 20+, t (694) = -1.065, p = .287) and

(2) ACT$_{math}$ (Full experimental, t (712) = .266, p = .790)
(ReMATCH$_{attempted}$ = 20+, t (679) = -.901, p = .368).

The experimental subgroup that attempted 39-40 ReMATCH problems was shown in previous analyses to differ significantly from the comparison group with regards to

(1) HSGPA (ReMATCH$_{attempted}$ = 39-40, t (600) = -3.902, p < .001) and

(2) ACT$_{math}$ (ReMATCH$_{attempted}$ = 39-40, t (588) = -2.548, p < .001).

Comfort-levels for the comparison group ranged from 1.8 – 4.3 out of 5 on the initial survey and 3.1 – 4.6 out of 5 on the final survey. The ranges for the full experimental group were very close to these: 1.9 – 4.4 for the initial comfort levels and 3.3 – 4.7 for the final comfort levels. All topics showed an increase in the average comfort-level of students from the initial to the final survey. On both surveys in 2006, students displayed the lowest levels of comfort with the topics of limiting reactants and theoretical yields.

Description of Student Comfort with Math-Related Chemistry Topics in 2007 – A Measure of Confidence

Table 52 displays the means and standard deviations of student responses to the comfort-level questions for students with ReMATCH$_{attempted}$ = 39-40 from the 2007 study. The data is split between students who viewed the lowest quartile of ReMATCH content pages and the highest quartile of ReMATCH content pages and is only included for students who responded to each topic on both the initial and final surveys. ANOVAs for each topic comparing the lowest quartile of page viewers with the highest quartile of page viewers for 2007 will be discussed in the next chapter, but the results of the analyses are also reported on Table 52. The groups of students with the lowest and highest quartiles of pages viewed were shown previously not to differ significantly in regards to HSGPA and ACT$_{math}$.

Comfort-levels for the group with the lowest quartile of Content Pages Viewed ranged from 2.5-4.4 out of 5 on the initial survey and 4.0-4.7 out of 5 on the final survey. The values for the group with the highest quartile of Content Pages Viewed ranged from 2.0-4.4 on the initial survey and 3.7-4.7 on the final survey. For all topics, students showed an increase in the average comfort-level from the initial to the final survey. For the initial survey, students in the lowest and highest quartiles of Content Pages Viewed displayed their lowest levels of comfort with the topics of limiting reactants and theoretical yields. For the final survey, students in the lowest viewing quartile displayed their lowest levels of comfort with the topic of limiting reactants, while students in the highest viewing quartile displayed their lowest levels of comfort with the topics of converting molarity and theoretical yield.

Discussion of Survey Responses

Significant portions of students in each of these studies completed the initial and final surveys. Descriptive information such as majors and high school math and science courses completed by KU general chemistry students increases the generalizability of ReMATCH to other institutions. The KU general chemistry courses typically consisted of 20-30% Pre-Medicine or Biology students, ~20% Engineering, ~13% Pre-Pharmacy, ~2% Chemistry students, and ~ 30 – 40% Other or Undecided. These students have the following high school math and science backgrounds: over 70% completed pre-calculus, ~50% completed calculus, over 95% completed chemistry, and ~75% completed physics. Once again, to order to gain a broad understanding of student confidence with math-related chemistry topics, survey questions regarding how *comfortable* they feel/felt with the topic were selected.

On the *comfort* questions for all topics in both years, the average level of comfort for the students increased from the initial to the final survey. In 2006, both the comparison group and the full experimental group had average responses that ranged from “Inclined to Disagree” to “Inclined to Agree” on the initial survey and from “Neutral” to “Strongly Agree” on the final survey. In 2007, students from the lowest quartile of Content Pages Viewed were compared to students from the highest quartile of Content Pages Viewed. A difference between the values for these groups was observed initially: the average responses from the lowest quartile of page viewers ranged from “Neutral” to

“Inclined to Agree”, while the responses from the highest quartile of page viewers ranged from “Inclined to Disagree” to “Inclined to Agree”. The final survey responses for these groups both ranged from “Inclined to Agree” to “Strongly Agree.”

Despite nearly all of the students having taken chemistry in high school, large portions of the students from both years initially reported not remembering the concept of the mole, limiting reactants, theoretical yield, and molarity. Within these values, however, a distinct difference in the percentage of students not remembering the topics existed between the group from 2006 and 2007. Smaller percentages of students from the 2007 survey reported not remembering a topic. This probably points to the difference in the total portion of general chemistry students from each year who completed the initial survey. The smaller portion of students completing the initial survey in 2007 most likely constituted a group of higher achieving students – those with higher academic aptitudes. It would be expected that higher achieving students would remember topics from their high school chemistry course with greater accuracy.

Table 51

Summary Statistics of Comfort-Level with Math-Related Chemistry Topics in 2006 and *T*-test Results for Comparison Group Versus Experimental Group and Experimental Subgroups

(Includes students with responses for each topic on both surveys)

Mean and Standard Deviation of Comfort-Level Associated with Each Topic[d]

		Comparison Group		**Experimental Group and Subgroups**					
I feel comfortable with …		All (n = 483)		All (n = 184)		20+ (n = 163)		39+ (n = 72)	
		Initial	Final	Initial	Final	Initial	Final	Initial	Final
Mole	*M*	3.1	4.2	3.4	4.3	3.4	**4.4**[a]*	**3.6**[b]	**4.6**[a c]
	SD	1.46	0.96	1.49	0.90	1.44	0.76	1.35	0.62
	T-Test Results			$t(665)$=-1.77	$t(665)$=-1.73	$t(639)$= -1.92	$t(639)$= -2.90	$t(553)$=-2.40	$t(127.5)$=-4.31
	Significance			p = .078	p = .083	p = .056	p = .004	p = .017	p < .001
Sig. Figs	*M*	3.7	4.3	3.7	4.3	3.7	4.4	3.6	4.3
	SD	1.17	0.87	1.25	0.79	1.16	0.76	1.15	0.78
	T-Test Results			$t(665)$=0.05	$t(665)$=-1.02	$t(639)$=-.55	$t(639)$=-1.26	$t(553)$= 0.32	$t(553)$=-0.43
	Significance			p = .954	p = .309	p = .582	p = .208	p = .753	p = .670
Scientific Notation	*M*	4.3	4.6	4.4	4.7[c]	4.4	**4.7**[a c] *	4.5	**4.9**[a c]
	SD	0.91	0.66	0.86	0.54	0.80	0.51	0.73	0.39
	T-Test Results			$t(665)$=-0.92	$t(402.5)$=-1.85	$t(639)$=-1.27	$t(363.2)$=-2.71	$t(553)$=-1.90	$t(143.2)$=-4.92
	Significance			p = .360	p = .065	p = .203	p = .007	p = .058	p < .001
Rounding	*M*	4.3	4.5	4.3	4.5	4.3	4.5	4.3	4.6
	SD	0.94	0.75	0.93	0.75	0.89	0.77	0.92	0.69
	T-Test Results			$t(665)$=-0.14	$t(665)$= 0.22	$t(639)$=-0.49	$t(639)$=-0.19	$t(553)$=0.62	$t(553)$=-1.15
	Significance			p = .888	p = .830	p = .627	p = .847	p = .951	p = .249
Converting Metric	*M*	3.6	3.9	3.7	4.0	3.8	4.1	3.8	**4.3**[a]*
	SD	1.18	1.10	1.16	0.99	1.10	0.97	1.15	0.88
	T-Test Results			$t(665)$=-0.97	$t(665)$=-1.12	$t(639)$=-1.41	$t(639)$=-1.54	$t(553)$=-1.35	$t(553)$=-2.53
	Significance			p = .334	p = .261	p = .159	p = .124	p = .177	p = .012
Converting g → mol	*M*	2.9	4.1	3.1	**4.3**[a]*	**3.2**[b]	**4.4**[a c]	**3.4**[b]	**4.6**[a c]
	SD	1.52	1.08	1.52	0.95	1.49	0.83	1.49	0.82
	T-Test Results			$t(665)$=-1.78	$t(665)$=-2.24	$t(639)$=-2.12	$t(358.8)$=-3.73	$t(553)$=-2.66	$t(111.3)$=-4.30
	Significance			p = .076	p = .025	p = .035	p < .001	p = .008	p < .001
Limiting Reactants	*M*	1.9	3.3	2.1	3.3	2.1	3.4	2.3	**3.8**[a]*
	SD	1.62	1.22	1.66	1.23	1.68	1.21	1.71	1.10
	T-Test Results			$t(655)$=-0.92	$t(665)$=-0.66	$t(639)$=-0.89	$t(639)$=-1.35	$t(553)$=-1.81	$t(553)$=-3.44
	Significance			p = .358	p = .511	p = .372	p = .177	p = .071	p = .001
Theoretical Yield	*M*	1.8	3.1	1.9	**3.4**[a]*	1.9	**3.5**[a]	**2.3**[b]	**3.9**[a c]
	SD	1.68	1.40	1.66	1.31	1.71	1.29	1.75	1.15
	T-Test Results			$t(665)$=-0.24	$t(665)$=-2.76	$t(639)$=-0.38	$t(639)$=-3.29	$t(553)$=-2.13	$t(104.7)$=-5.21
	Significance			p = .811	p = .006	p = .708	p = .001	p = .034	p < .001
Molarity	*M*	2.3	3.6	2.6	**3.9**[a c] *	**2.7**[b]	**3.9**[a c]	**3.0**[b c]	**4.1**[a c]
	SD	1.65	1.16	1.62	1.01	1.64	0.97	1.49	0.86
	T-Test Results			$t(665)$=-1.82	$t(377.2)$=-2.43	$t(639)$=-2.17	$t(331.6)$=-3.14	$t(98.6)$=-3.40	$t(114.2)$=-4.34
	Significance			p = .069	p = .016	p = .030	p = .002	p = .001	p < .001

a Mean of group on final survey differs significantly from mean of Comparison Group mean on final survey.
b Mean of group on initial Survey differs significantly from mean of Comparison Group mean initial survey.
c Due to a significant Levene's test, the *t*-test statistics reported here do not assume equal variance.
d Scale used: 1=Strongly Disagree 2=Inclined to Disagree 3=Neutral 4=Inclined to Agree 5=Strongly Agree
* Largest experimental group/subgroup per topic exhibiting means that are significantly different from the comparison group on the final survey but not on the initial survey. Therefore, final mean difference between groups is attributable to use of ReMATCH.

Table 52

Summary Statistics of Comfort-Level with Math-Related Chemistry Topics in 2007 and *T*-test Results Comparing Groups of Low versus High Content Pages Viewed
(Includes students with $\text{ReMATCH}_{attempted}$ = 39-40 and responses for each topic on both surveys)

Mean and Standard Deviation of Comfort-Level Associated with Each Topic[d]

I feel comfortable with …		**Lowest 25% of Pages Viewed** (n = 75) Initial	**Lowest 25% of Pages Viewed** (n = 75) Final	**Highest 25% of Pages Viewed** (n = 102) Initial	**Highest 25% of Pages Viewed** (n = 102) Final
Mole	*M*	3.9	4.6	**3.3**[b c] *	4.5
	SD	1.11	0.75	1.46	0.64
			T-Test Results	t (174.8) = 3.13	t (175) = 2.24
			Significance	p = 0.002	p = 0.563
Sig. Figs	*M*	3.9	4.5	**3.4**[b c] *	4.4
	SD	1.08	0.74	1.38	0.82
			T-Test Results	t (174.3) = 2.80	t (175) = 1.18
			Significance	p = 0.006	p = 0.242
Scientific Notation	*M*	4.4	4.7	4.3	4.7
	SD	0.81	0.72	1.01	0.54
			T-Test Results	t (175) = 0.64	t (175) = -0.07
			Significance	p = 0.525	p = 0.947
Rounding	*M*	4.4	4.6	4.2	4.6
	SD	0.88	0.74	0.96	0.65
			T-Test Results	t (175) = 1.14	t (175) = 0.21
			Significance	p = 0.256	p = 0.837
Converting Metric	*M*	3.8	4.2	**3.4**[b c] *	4.1
	SD	1.11	0.84	1.21	1.03
			T-Test Results	t (167.0) = 2.14	t (175) = 1.11
			Significance	p = 0.034	p = 0.267
Limiting Reactants	*M*	2.6	4.0	**2.0**[b c] *	3.9
	SD	1.65	1.10	1.41	1.04
			T-Test Results	t (143.9) = 2.26	t (175) = 1.09
			Significance	p = 0.025	p = 0.276
Theoretical Yield	*M*	2.5	4.3	**2.0**[b]	**3.8**[a]
	SD	1.71	0.96	1.53	1.08
			T-Test Results	t (175) = 2.24	t (175) = 3.13
			Significance	p = 0.026	p = 0.002
Molarity	*M*	3.2	4.2	**2.4**[b]	**3.7**[a]
	SD	1.51	1.03	1.46	1.11
			T-Test Results	t (175) = 3.37	t (175) = 2.60
			Significance	p = 0.001	p = 0.010

a Final mean for Highest 25% group was significantly lower than final mean for Lowest 25% group.
b Initial mean for Highest 25% group was significantly lower than initial mean for Lowest 25% group.
c Due to a significant Levene's test, the t-test statistics reported here do not assume equal variance.
d Scale used: 1=Strongly Disagree 2=Inclined to Disagree 3=Neutral 4=Inclined to Agree 5=Strongly Agree
* Topics for which Highest 25% group differed significantly from Lowest 25% group on initial survey but not on final survey. Therefore, the removal of the initial difference that existed between the groups was attributed to accessing more ReMATCH tutorial pages since groups did not differ on HSGPA or ACT_{math} and students in both group tried the same number of ReMATCH problems.

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Chapter 9

Addressing Hypothesis Two from 2006 and 2007 Study

– Results and Discussion of Survey Responses Regarding Comfort as a Measure of Confidence

2006 Hypothesis Two: Student confidence with the math-related chemistry topics would differ significantly at the end of the semester between students completing the ReMATCH assignments and students using the self-study approach.

2007 Hypothesis Two: Student confidence with the math-related chemistry topics would differ significantly between the groups of students completing different amount of the tutorial assignments or viewing different amounts of the ReMATCH tutorial pages.

Effect of ReMATCH Use on Comfort with Math-Related Chemistry Topics in 2006

To determine whether being assigned to the 2006 experimental group improved student comfort with the introductory math-related chemistry topics beyond the improvement seen for students in the comparison group, *t*-tests were conducted relating the mean initial or final comfort-levels of the comparison and the full experimental groups for each topic. These *t*-tests were conducted separately for the initial and final surveys. For each topic, Table 51 displays the results from this comparison in the row titled *T-Test Results* for the column labeled *All*; these results appear directly below the mean and standard deviation for the survey administration of interest. Only students with responses to each comfort question on both surveys were used in this analysis. Based on this data, on the initial survey, the comparison group and the full experimental group did not differ significantly in their perceived comfort-level with any of the topics. Any differences that are significant between an experimental group and the comparison group are indicated in Table 51 by **bolding** and by the presences of an asterisk (*****). On the final survey, the comparison and full experimental groups were shown to differ significantly on the following three topics:

(1) converting grams to moles,

(2) the concept of theoretical yield, and

(3) the concept of molarity.

For each of these three cases, despite statistically similar initial values, the experimental group had a significantly higher perceived level of comfort than the comparison group on the final survey.

To determine whether recorded interactions with the ReMATCH tutorial improved student-perceived comfort-level with any of these topics, the survey responses of the comparison group were also compared to the survey responses of the 20+ subgroup of the experimental group. This experimental subgroup was shown previously not to differ from the comparison group in their HSGPA and ACT_{math} values. For most of the topics, this 20+ subgroup did not differ significantly from the comparison group for initial comfort-levels with the topics; the only exceptions were the following two topics (1) converting grams to moles and (2) concept of molarity; for which, the 20+ group had significantly higher initial levels of comfort (Table 51). For each topic, Table 51 displays the results from these *t*-tests in the row titled *T-Test Results* for the column labeled *20+*. Responses on the final survey indicated that the 20+ subgroup differed significantly from the comparison group on the same three topics from the full experimental group, plus the two additional topics listed below:

(4) the concept of the mole in chemistry and

(5) the use of scientific notation.

Again, the final comfort-levels of the experimental subgroup were significantly higher than those of the comparison group. Since the initial values of the groups did not differ significantly but the final values did, it appears that interacting with the tutorial is having a positive impact on student perceived comfort-level for the concept of the mole in chemistry and the use of scientific notation.

Finally, a similar analysis was performed comparing the comfort-levels of the comparison group to those in the 39+ subgroup of the experimental group. Analyzing the initial survey responses showed that the comparison and 39+ subgroup differed significantly on four of the nine topics. These were (1) the concept of the mole in chemistry, (2) converting grams to moles, (3) the concept of theoretical yield, and (4) the concept of molarity. Each of these topics, however, are ones for which the comparison and experimental groups have already been shown to differ with regards to the final survey (Table 51). For each topic, Table 51 displays the results from these *t*-tests in the row titled *T-Test Results* for the column labeled *39+*. Two additional topics became significant for the first time for the *t*-tests comparing the 2006 comparison and 39+ group:

(6) converting metric and

(7) the concept of limiting reactants.

For these last two significant topics, the 39+ experimental group showed significantly higher perceived comfort-levels on the final survey, yet comfort-levels that were not significantly different on the initial survey. Because students had to attempt more ReMATCH problems before their comfort on these two topics differed significantly, it is probably that this material was not covered until closer to the end of the 40 ReMATCH homework set and tutorial pages that assisted students with these topics.

Based on these three sets of analyses, only two topics exhibited no significant differences in comfort as reported on the final survey between the comparison group and any version of the experimental group:

(1) the use of significant figures and

(2) the use of rounding.

Considering that these are the two most general topics that are mentioned on the surveys and are topics likely to be found in many of the math courses that the students took in high school or college prior to taking chemistry, it is not surprising that ReMATCH-use did not have an impact on student perceived comfort-levels for these topics (Table 51).

Effect of ReMATCH Use on Comfort with Math-Related Chemistry Topics in 2007

For 2007 data, *T*-tests were also used to examine the effect of tutorial-use on student perceived comfort-level with the math-related chemistry topics. Since most students attempted 39-40 ReMATCH problems in 2007, the analysis for 2007 was conducted within the group of students who attempted 39+

ReMATCH problems. Therefore, different levels of tutorial users were differentiated in this group based on the number of ReMATCH Content Pages Viewed. Because no true comparison group existed in 2007, the *t*-tests compared students in the lowest quartile of Content Pages Viewed (Viewed 0 – 10 unique pages) to those in the highest quartile of Content Pages Viewed (Viewed 44 – 88 unique pages).

Table 52 shows the means and standard deviations for each group along with the results from the *t*-tests comparing their mean comfort-level for each topic on either the initial or final survey. From this comparison for the initial survey, significant differences in student-perceived comfort-level existed between the lowest quartile and highest quartile of Content Pages Viewed on the initial survey for six of the eight topics:

(1) the concept of the mole in chemistry,

(2) using significant figures,

(3) converting metric units,

(4) the concept of limiting reactants,

(5) the concept of theoretical yield, and

(6) the concept of molarity.

For the final survey, the quartiles only differed significantly on two topics (Table 52): (1) the concept of theoretical yield and (2) the concept of molarity. Though these two stayed significantly different from initial to final surveys for the quartiles, it should be noted that the highest quartile had a greater gain in comfort than the lowest quartile for the concept of molarity; and, the two quartiles had identical gains in the concept of theoretical yield. Additionally, the largest differences in comfort-level gains to exist between the quartiles occurred for (1) the concept of the mole in chemistry and (2) the concept of limiting reactants. For each of these, the highest quartile group had a comfort level gain that was one-half of a Likert-scale unit greater than the lowest quartile group. In combination with the findings from the initial survey, the following conclusion can be drawn:

(1) students with lower initial comfort-levels on these topics tended to view more of the tutorial pages than students with higher initial comfort-levels, and

(2) students with lower initial comfort-levels on these topics who accessed at least half of the ReMATCH content pages no longer displayed significantly lower comfort levels on the final survey.

The highest quartile of Content Pages Viewed, despite having lower initial levels of comfort with the math-related chemistry topics, experienced a greater average increase in comfort for most of the topics between the times of the initial and final surveys – a greater gain in comfort-level than that experienced by the lowest quartile of Content Pages Viewed.

An attempt was made to identify what differences, other than ReMATCH tutorial pages accessed, could have resulted in this greater gain in comfort. Knowing that the HSGPA and ACT_{math} scores were similar for these groups, a *t*-test was used to compare the mean Percent Homework values for both groups. The Percent Homework values did not differ significantly between the groups, $t(252) = -.667$, $p = .506$ ($M_{1st\ quartile} = 87.5$ %, $SD = 11.51$, $n = 122$; $M_{4th\ quartile} = 88.4\%$, $SD = 10.66$, $n = 132$). Therefore, the possibility that the highest quartile students overcame their initially lower levels of comfort by completing significantly more homework for the course than the lowest quartile students was not supported. The lack any other identifiable differences in the course experiences of these groups supported the possibility that the greater increase in student perceived-comfort with several of the math-related chemistry topics could at this time be attributed to ReMATCH use and be due to students having greater interaction with the ReMATCH tutorial webpages.

To determine if the students viewing more content pages were using other aspects of the ReMATCH tutorial differently, another *t*-test was performed to examine the average number of attempts per problem for the highest and lowest quartiles of Content Pages Viewed. This analysis confirmed that students in these two groups differed significantly in the number of attempts they took for each ReMATCH problem, $t(242.776) = -6.512$. $p < .001$ ($M_{1st\ quartile} = 3.6$, $SD = 1.71$, $n = 122$; $M_{4th\ quartile} = 5.3$, $SD = 2.26$, $n = 132$). This supported the idea that students viewing more ReMATCH content pages were doing so while attempting the ReMATCH homework problems a greater number of times. Since, in this analysis, students in both the highest and lowest quartiles attempted the same number of ReMATCH homework problems (39+), the greater number of attempts per problem and greater number of content pages viewed by students in the highest quartile group was equated to a greater amount of time spent actively engaged with the ReMATCH tutorial.

Discussion of Survey Responses to Comfort Questions – Implications for Student Confidence

Hypothesis Two for 2006 Rewritten with Emphasis:

Student confidence with the math-related chemistry topics would **differ** *significantly* at the **end** of the semester between

(1) students **completing** the ReMATCH assignments = 39+ AND

(2) students using the self-study approach. = Comparison Group

- However this significant difference would only be meaningful if the groups did not differ significantly on the initial survey.
- Hypothesis makes no claim regarding the difference having to take the form of a greater final value or a greater gain score. – therefore, significant differences could also arise from reductions in the variances around the means of each group.

Addressing Hypothesis Two required the comparison of *student comfort-levels* with individual topics on the initial survey for the 2006 comparison group and the full 2006 experimental group – or, one of its subgroups of interest. When *t*-tests of the initial levels of these groups did not differ significantly, but *t*-tests of the final levels did differ significantly, this supported the hypothesis that the difference was due to ReMATCH use. *T*-tests examining relationships between the comparison group and each of the individual experimental groups focused on different aspects of what was meant by *ReMATCH use*. *T*-tests between the comparison group and the

(1) full experimental group focused on whether simply being assigned to a lab section including ReMATCH as a graded element had any significant effect on student comfort-levels with math-related chemistry topics.

— Prior comparisons in these studies show that these groups demonstrate no significant differences in HSGPA or ACT_{math}.

(2) 20+ experimental subgroup focused on whether interacting with at least half of the ReMATCH homework problems had any significant effect on student comfort-levels with math-related chemistry topics.

— Prior comparisons in these studies show that these groups demonstrate no significant differences in HSGPA or ACT_{math}.

(3) 39+ experimental subgroup focused on whether trying all of the ReMATCH homework problems – using ReMATCH as it was designed to be used – had any significant effect on student comfort levels with math-related chemistry topics.

— Prior comparisons in these studies show that these groups have significantly different mean values for HSGPA or ACT_{math}.

Because Hypothesis Two emphasizes differences due to students *completing* the ReMATCH assignments, any topic with a significantly different final comfort-level but no significantly different initial level in comparisons of the 39+ experimental group and the comparison group was considered particularly interesting. These topics included (1) using scientific notation, (2) converting between metric units, and (3) the concept of limiting reactants. An additionally interesting point for the "using scientific notation" topic is that the statistically significant difference in final comfort-levels was also present for the 20+ experimental subgroup. For the other two topics the significant difference was not seen until the 39+ level.

Based on these findings, it appears that *completing* the ReMATCH assignments provides students in the 39+ subgroup additional experiences not pursued by students in the comparison group that particularly foster a student's comfort with converting metric units and the concept of limiting reactants. Furthermore, it should be noted that the sizes of these significant differences were around one-half of a Likert-scale unit. Additionally, when gain scores were examined for each of these experimental groups versus the comparison group for each topic from the initial to final survey, no significant differences were found to exist (data not provided). Therefore, it appears that the significant differences observed in the final comfort-levels for these two topics were more likely due to a reduction in variance observed between their initial and final comfort-levels rather than being due to an overall greater gain in confidence. This supports the idea that ReMATCH met one of its design goals of "leveling the playing field" for general chemistry students. By providing students with diverse initial comfort-levels an environment in which they can work and, thereby, develop an understanding and comfort with the topics, ReMATCH was able to reduce the variance in student comfort-levels for some topics when students actively engaged with the system as the 39+ experimental group did on average.

By the above reasoning, the fact that the significant difference in final comfort-levels between ReMATCH users and the comparison group first became visible for the topic of scientific notation for the 20+ experimental subgroup can be explained by the first half of the ReMATCH assignments consisting of many opportunities for students to practice and receive immediate feedback on their use of scientific notation. The other topics that were significant for the 20+ level included (1) the concept of the mole in chemistry and (2) the concept of theoretical yield. For the concept of the mole, the presence of a significant difference between the comparison and the 20+ experimental subgroup is understandable because of the heavy emphasis on this quantity from nearly the beginning of the ReMATCH tutorial. For the 39+ subgroup, the majority of the students were on average more comfortable with the mole concept initially than the comparison students were. The impact of this significant initial difference is visible in the 39+ group making it difficult to attribute the significant final difference for this group to their ReMATCH use. However, because of its significance for only the final survey for the 20+ group we can feel confident that ReMATCH use is increasing the comfort on average of the more diverse group of students represented in the 20+ group.

On a 5-point Likert-scale, there is not much room for improvement if many of the students begin the course feeling relatively comfortable with a topic. This explanation probably accounts for why no significant differences were seen at any level for the topics of rounding and significant figures for the 2006 analyses. On topics where students typically begin with lower levels of comfort, some students will also begin the course feeling very comfortable with the topics; on a 5-Point Likert-scale, there is not much room (if any) for these students to improve. Therefore, all that can happen over the semester is for other students to increase their comfort levels, such that on a final survey the variance has undergone a significant change (as the originally less comfortable students have caught up with their peers) even if the overall change in the mean is relatively small.

Hypothesis Two 2007 Rewritten with Emphasis:

Student confidence with the math-related chemistry topics would **differ** *significantly* between

(1) groups of students **completing** different amounts of the tutorial assignments or
(2) viewing different amounts of the ReMATCH tutorial pages.

Since the students in the 2007 group interacted with ReMATCH to a remarkably different degree than the experimental group did in 2006, Hypothesis Two needed some revisions before being tested on the 2007 students. Because of the exceptionally large portion of students who attempted all of the ReMATCH problems in 2007, comparing groups of students who completed differing amounts of the tutorial assignments was no longer a statistically feasible option; sample sizes varied too greatly. Therefore, all comparisons regarding Hypothesis Two in 2007 occurred within the group of students who attempted 39-40 ReMATCH homework problems. Adhering to the remainder of the original idea of Hypothesis Two, which regards examining the effect on student confidence with math-related chemistry topics between groups of students viewing different amounts of the ReMATCH tutorial pages, the analysis in 2007 compared student comfort-levels as reported on the initial and final surveys. By conducting this analysis for each math-related chemistry topic just within the group of students who attempted 39-40 problems, some of the possible sources of variance between and within each of the Content Pages Viewed groups were reduced. Because students could have had many reasons for viewing an intermediate number of content pages while attempting all 40 of the ReMATCH problems – especially given that the number of content pages viewed was not a graded component of ReMATCH, the decision was made to compare via *t*-tests only the groups from the lowest quartile (0-10 unique pages) and highest quartile (44-88 unique pages) of Content Pages Viewed.

The first interesting result of this approach was the realization that it was not mainly the final student comfort-levels that differed significantly between the lowest and highest quartiles but that mainly the initial levels that differed between these groups. Based on the *t*-tests of the initial comfort levels between these two groups, the ReMATCH users in the highest quartile of page viewers had significantly lower initial levels of comfort compared to the lowest quartile of page viewers about six of the eight math-related chemistry topics. *T*-tests of final comfort-levels indicated that only two of these originally significant differences remained statistically significant. This indicates that (1) students with significantly lower initial comfort levels were likely to view more tutorial pages and that (2) students with significantly lower initial comfort levels who viewed at least half of the ReMATCH content pages no longer displayed significantly lower comfort levels on the final survey for most topics.

Further analyses into possible explanations for how most of these significant initial differences were removed over the semester showed that these were not due to differences in the number of WebAssign ® homework points the students obtained. It was determined that the highest quartile had a significantly greater number of attempts for each ReMATCH problem (5.3 attempts/problem) than the lowest quartile had (3.6 attempts/problem). It is clear that the highest quartile of viewers are viewing more pages while making more attempts (on average) to solve the homework problems correctly. At this point, it is not possible to further isolate the impact of ReMATCH tutorial pages within these groups. However, it was deemed reasonable to believe that students who are attempting individual problems multiple times and accessing larger numbers of ReMATCH content pages to obtain the help in this endeavor are probably highly engaged in their learning process. Such metacognitive and engaged learning skills are presented in ReMATCH, but it is impossible to determine at this point whether the students had those skills to begin with or gained them through the use of ReMATCH.

Chapter 10

Addressing Hypothesis Three from 2006 and 2007 Studies

– Results and Discussion of ReMATCH Interaction and Attitude Questions

2006 Hypothesis Three: Within the group of students assigned to use the ReMATCH tutorial, students who completed more of the assignments or spent more time on the assignments would report more positive attitudes towards the tutorial.

2007 Hypothesis Three: Within the group of students who completed the ReMATCH assignments, students who viewed more of the ReMATCH tutorial pages would report more positive attitudes towards the tutorial.

ReMATCH-User Survey Responses Regarding Tutorial Interactions and Attitudes

On the final survey for both years, students who were required to complete the tutorial assignments answered questions regarding when they began the tutorial, how long they spent working on it, how easy it was to interact with, their attitudes towards it, and the appropriateness of the material that it covered. The specific questions, along with the frequency of student responses, are shown in Table 53. In both years, most students assigned to complete the ReMATCH tutorial assignments for a grade began interacting with the website during the first or second week of the course, a total of 89.2% from 2006 and 88.0% from 2007. Additionally, the percentage of survey responders from both years who reported putting off the tutorial assignments until after the first or second exam were ~1% and 0.5%, respectively. The amount of time that students reported working on the tutorial assignments differed quite a bit for all except those students who only spent roughly 1-2 hours on it total, which was a bit under 10% for each year. Regarding the students who reported spending longer periods of time on the ReMATCH tutorial and homework, it appears that in 2006, ReMATCH users spent relatively more time on each assignment than the 2007 users did. In 2006, when ReMATCH was a required assignment only for the experimental group, the large portion of students thought that ReMATCH should cover less material; however, when in 2007 it was required for all general chemistry students a much larger portion of the students believed that the amount of material covered by ReMATCH should stay the same. Finally, when the ReMATCH users from both years were asked about how much of the material covered in ReMATCH they used in their general chemistry course over the semester, roughly twice as many students in 2006 than in 2007 reported that they used *none of it*, 9.7% and 4.5%, respectively. Whereas, approximately 55% reported that they used *some of it* in 2006, nearly 56% reported that they either used *most of it* or *all of it*.

Factor Analysis of Interactions with ReMATCH from Final Survey Data

The final survey items regarding student attitude towards the ReMATCH system and their interactions with it were analyzed using factor analysis to determine whether one or more underlying attributes of ReMATCH were associated with some students using the tutorial more than others. The survey questions included in this analysis all asked about students' feelings towards and interactions with ReMATCH. For each of these questions, students responded on the following 5-point Likert-scale:

(1) Strongly Disagree
(2) Inclined to Disagree
(3) Neither
(4) Inclined to Agree, and
(5) Strongly Agree.

The following survey items were included in the separate principal component factor analyses for both 2006 and 2007 (except where the question is explicitly associated with only 2007):

Table 53

Percentage of Students Selecting Each Response to the Survey Questions for Both Years

Survey Questions Related to Student Interactions with ReMATCH and Attitudes Regarding ReMATCH	2006 Exp. (%)	2007 (%)
When did you start to use the ReMATCH tutorial/homework?	*n* = 211	--
The week it was announced in class (first week of classes)	12.4	N/A
The week it was announced in lab (second week of classes)	76.8	
Before the first exam	5.9	
Between the first exam and the second exam	1.1	
After the second exam	.5	
Never	3.2	
When did you start to use the ReMATCH tutorial/homework?	--	*n* = 627
Immediately after it was announced in class (during the first full week of class)	N/A	32.7
Before the first Math Tutorial Assignment was due (the second week of class)		55.3
After one or more of the Math Tutorial Assignments were due but before the last Math Tutorial Assignment was due		4.1
A day or two before the first exam		4.1
Between the first exam and the second exam		1.0
After the second exam		0.6
Never		2.1
Approximately how much time in all did you spend on the ReMATCH tutorial and/or working on the tutorial assignments?	*n* = 186	*n* = 628
1-2 hours total (average of 15-30 minutes per assignment)	9.7	9.6
2-4 hours total (average of 30-45 minutes per assignment)	14.0	25.5
4-7 hours total (average of 1-2 hours per assignments)	25.3	33.1
8-11 hours total (average of 2-3 hours per assignment)	23.7	16.1
12-15 hours total (average of 3-4 hours per assignment)	11.3	6.7
16-19 hours total (average of 4-5 hours per assignment)	16.1	4.1
20-23 hours total (average of 5-6 hours per assignment)	N/A	2.1
24-28 hours total (average of 6-7 hours per assignment)		0.8
29 or more hours total (average of 7 or greater hours per assignment)		1.1
None because I did not use ReMATCH or do the Math Tutorial Assignments		1.0
I think that ReMATCH and the tutorial assignments should …	*n* = 211	*n* = 627
cover less material.	39.2	28.2
stay the same.	25.8	56.8
cover more material.	31.7	13.2
I did not use ReMATCH or do the Tutorial Assignments.	3.2	1.8
How much of the material covered in ReMATCH and the tutorial assignments did you use in your general chemistry course this semester?	*n* = 211	*n* = 628
None of it	9.7	4.5
Some of it	54.8	38.1
Most of it	20.4	39.0
All of it	12.4	16.7
I did not use ReMATCH or do the Tutorial Assignments.	2.7	1.8

(a) My overall experience with ReMATCH and the Math Tutorial Assignments was good.

(b) I found the ReMATCH tutorials to be easy to read.

(c) I found the language used in the ReMATCH tutorials easy to understand.

(d) I found the ReMATCH tutorial website easy to navigate.

(e) The ReMATCH tutorials and the Math Tutorial Assignments covered topics that were stressed in class.

(f) I feel the ReMATCH tutorials aided my understanding of the material in the course.

(g) The ReMATCH tutorials provided me with additional information on some of the material that was necessary for this general chemistry course.

(h) I found the material in the ReMATCH tutorials and Math Tutorial Assignments applicable to the course exams.

(i) I found the explanations given for the different topics in the ReMATCH tutorial helpful.

(j) I feel that using ReMATCH was worth my time.

(k) I found the everyday examples and practice problems given in the ReMATCH tutorial pages beneficial to my understanding of the chemistry concepts (2007 only).

Three criteria were used to determine the number of factors to rotate: the scree test (2006, Figure 44; 2007,Figure 45), eigenvalues greater than one (2006, Table 54; 2007 Table 55), and the interpretability of the factor solution. The scree test and eigenvalues greater than one both indicated the presence of two factors for both years of the analysis; these were rotated using a Varimax rotation procedure. The rotated solution, as shown in Table 56, produced the same two interpretable factors for each year: *relevancy* of ReMATCH and *accessibility* of ReMATCH. The relevancy factor accounted for 56.2% of the item variance in 2006 and 58.3% in 2007, while the accessibility factor accounted for 10.5% of the item variance in 2006 and 10.9% in 2007. Each item loaded onto only one factor, and the same items loaded onto the same factors for both years (the additional question in 2007 loaded onto the relevancy factor).

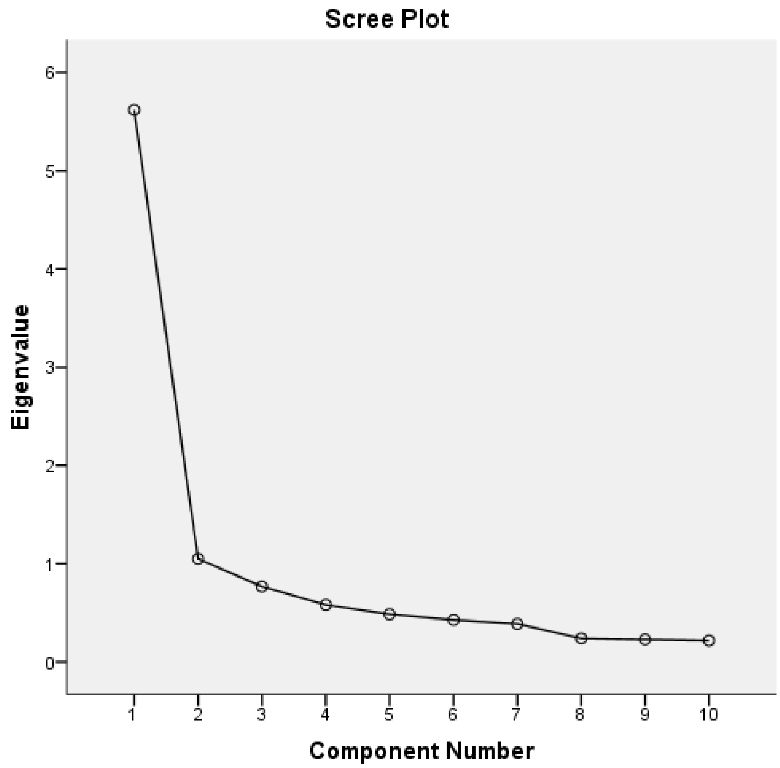

Figure 44 Displays Scree Plot for 2006 Factor Analysis indicating the presence of two factors.

Table 54

2006 Factor Analysis – Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Vari-ance	Cumula-tive %	Total	% of Vari-ance	Cumula-tive %	Total	% of Vari -ance	Cumula-tive %
1	5.62	56.19	56.19	5.62	56.19	56.19	4.32	43.15	43.15
2	1.05	10.50	66.68	1.05	10.50	66.68	2.35	23.54	66.68
3	.77	7.67	74.35						
4	.58	5.81	80.16						
5	.49	4.85	85.01						
6	.43	4.27	89.28						
7	.39	3.87	93.15						
8	.24	2.39	95.55						
9	.23	2.28	97.83						
10	.22	2.17	100.0						

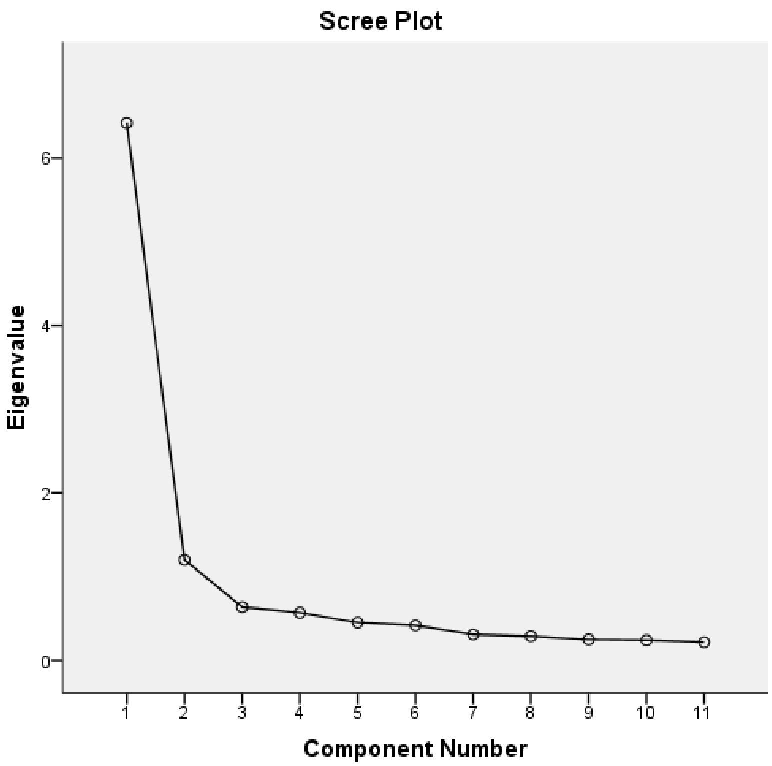

Figure 45 Displays Scree Plot for 2007 Factor Analysis indicating the presence of two factors.

Table 55

2007 Factor Analysis - Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Vari-ance	Cumula-tive %	Total	% of Vari-ance	Cumula-tive %	Total	% of Vari -ance	Cumula-tive %
1	6.418	58.346	58.346	6.418	58.346	58.346	5.027	45.703	45.703
2	1.201	10.922	69.268	1.201	10.922	69.268	2.592	23.565	69.268
3	.636	5.781	75.049						
4	.569	5.169	80.218						
5	.453	4.114	84.333						
6	.418	3.803	88.136						
7	.310	2.817	90.953						
8	.288	2.617	93.570						
9	.249	2.266	95.836						
10	.240	2.184	98.020						
11	.218	1.980	100.000						

Variables consisting of overall values for each factor were created for the separate years by adding together the student scores on each item while weighting each score by that item's loading-weight. This created the following equations, where the lowercase letters correspond to the questions identified for each factor in Table 56 (and on the preceding page):

$$\text{Relvancy}_{2006} = .721*(a) + .630*(e) + .820*(f) + .805*(g) + .777*(h) + .718*(i) + .831*(j) \quad (4)$$

$$\text{Accessibility}_{2006} = .760*(b) + .794*(c) + .805*(d) \quad (5)$$

$$\text{Relevancy}_{2007} = .678*(a) + .617*(e) + .870*(f) + .830*(g) + .808*(h) + .730*(i) + .831*(j) + .794\ (k) \quad (6)$$

$$\text{Accessibility}_{2007} = .800*(b) + .839*(c) + .795*(d) \quad (7)$$

The resulting values for the relevancy factor ranged from 5.30 – 26.51 with a mean of 13.17 out of 35 possible points in 2006 and from 6.15 – 30.74 with a mean of 20.34 out of 40 possible points in 2007. The accessibility factor ranged from 2.36 – 11.80 with a mean of 6.93 in 2006 and from 2.43 – 12.17 with a mean of 8.74 in 2007 out of 15 possible points for both years. Dividing each of the means above by the total possible points for the factor and then multiplying by 5 returns the mean for each of the factors in terms of the original 5-point Likert-scale. Based on this calculation, the mean for relevancy in 2006 on the Likert-scale was 1.88, between the choices of *inclined to disagree* and *strongly disagree*. The mean for relevancy in 2007 on the Likert-scale was 2.54, between *neither* and *inclined to disagree*. The mean for accessibility in 2006 was 2.31 (between *neither* and *inclined to disagree*); and, in 2007, it was 2.91 (close to the answer choice of *neither*). An ANOVA conducted with the 2006 data indicated that experimental students with different $\text{ReMATCH}_{\text{attempted}}$ levels did not differ significantly on the relevance factor, $F\ (2, 174) = 2.130$, $p = .122$, but did differ significantly on the accessibility factor, $F\ (2, 176) = 4.438$, $p = .013$. For the 2007 data, a similar analysis was performed that compared the means for each factor for students at different levels of Content Pages Viewed within the group of students who attempted 39-40 ReMATCH problems. This analysis showed that neither factor differed significantly across these groups: for relevance factor, $F\ (2, 512) = 0.973$, $p = .379$ and

Table 56

Separate Rotated Component Matrices[a] for 2006 & 2007 Factor Analyses

Final Survey Items Related to Student Feelings about ReMATCH	2006 Component 1	2006 Component 2	2007 Component 1	2007 Component 2
(a) My overall experience with ReMATCH and the Math Tutorial Assignments was good.	.721		.678	
(b) I found the ReMATCH tutorials to be easy to read.		.760		.800
(c) I found the language used in the ReMATCH tutorials easy to understand.		.794		.839
(d) I found the ReMATCH tutorial website easy to navigate.		.805		.795
(e) The ReMATCH tutorials and the Math Tutorial Assignments covered topics that were stressed in class.	.630		.617	
(f) I feel the ReMATCH tutorials aided my understanding of the material in the course.	.820		.870	
(g) The ReMATCH tutorials provided me with additional information on some of the material that was necessary for this general chemistry course	.805		.820	
(h) I found the material in the ReMATCH tutorials and Math Tutorial Assignments applicable to the course exams.	.777		.808	
(i) I found the explanations given for the different topics in the ReMATCH tutorial helpful.	.718		.730	
(j) I feel that using ReMATCH was worth my time.	.831		.831	
(k) I found the everyday examples and practice problems given in the ReMATCH tutorial pages beneficial to my understanding of the chemistry concepts.	N/A		.794	

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

for accessibility, F (2, 513) = 0.758, p = .469. This indicated that students viewing different numbers of content pages were not due to them having an easier or harder time interacting with the ReMATCH website nor was it due to them viewing the material as significantly more or less related or necessary to the course. On average, the students did not perceive the material as very relevant to the course, and they were neutral regarding its accessibility through the ReMATCH website.

Correlations Between Background Variables and the ReMATCH Relevancy and Accessibility Factors in 2006

Correlations between the two factors and the demographic and academic background variables were calculated to determine whether any relationships existed between student relevancy and accessibility and student background. In 2006, each factor had a significant negative correlation with only one background variable:

(1) the relevancy factor correlated negatively with $\text{Status}_{\text{enrolled}}$ = Prior Junior or Senior and
(2) the accessibility factor correlated negatively with $\text{Status}_{\text{entry}}$ = Transfer (and $\text{Status}_{\text{enrolled}}$ = First Semester Transfer).

There could be issues with students taking this course later in their academic career not being as interested in finding the connections present between ReMATCH and the course – they simply may not have as much commitment to the course in general. Additionally, transfer students tend to take this course as more advanced students (junior or seniors), so it could be that both findings above are really reflecting the same students. With the number of outside commitments that nontraditional students tend to have, it is easy to understand how they could find ReMATCH less accessible due to their own lack of time to devote to it. Along the same lines, transfer students and upper classmen are more likely to live off-campus; therefore, ReMATCH may have been less accessible to them because of a less accessible internet connection.

In 2006, correlations were also calculated for the relevancy and accessibility factors with course performance and interactions with ReMATCH, specifically the variables included the following:

Percent Exam Points,

$\text{ReMATCH}_{attempted} = 5\text{-}28$

$\text{ReMATCH}_{attempted} = 29\text{-}38$

$\text{ReMATCH}_{attempted} = 39\text{-}40$

Began ReMATCH,

Total ReMATCH Time,

ReMATCH Logins,

Total Attempts, and

Attempts /Problem.

In 2006, the relationships with the course performance and ReMATCH interaction variables that were significant for each of the factors include the following:

(1) accessibility was significantly negatively correlated with $\text{ReMATCH}_{attempted} = 5\text{-}28$

(2) accessibility was significantly positively correlated with $\text{ReMATCH}_{attempted} = 39\text{-}40$

(3) relevancy was positively correlated with Percent Exam Points,

(4) relevancy was negatively correlated with Total ReMATCH Time, and

(5) accessibility was positively correlated with Total Attempts.

While accessibility is significantly correlated with two levels of the $\text{ReMATCH}_{attempted}$ variable, the relevancy factor is not correlated with any of the dichotomous versions of the $\text{ReMATCH}_{attempted}$ variable.

Correlations Between Background Variables and the ReMATCH Relevancy and Accessibility Factors in 2007

In 2007, the same correlational analysis was performed between the background variables and the relevancy and accessibility factors. This was again followed by a correlational analysis between the factors and student course performance and interactions with ReMATCH, using the same variables as in 2006. However, this time, the analyses were performed for only those students who attempted 39-40 ReMATCH problems. In the analysis with background variables, many more significant correlations existed than were present in 2006. In 2007, the relationships that were significant between one or both of the factors for these variables include the following:

(1) both factors have significant positive correlations with ACT_{math} scores,

(2) both factors have significant negative correlations with $Last_{math}$ = College Algebra, Trigonometry, and Pre-Calculus,

(3) the relevancy factor has a significant negative correlation with Caucasian,

(4) the relevancy factor has a significant positive correlation with Asian,

(5) the relevancy factor has a significant positive correlation with $Status_{entry}$ = Other,

(6) the accessibility factor has a significant positive correlation with HSGPA, $ACT_{composite,}$ First Semester Freshman, and No College Math, and

(7) the accessibility factor has a significant negative correlation with $Status_{enrolled}$ = Prior Freshmen.

When the analyses were run with the course performance and ReMATCH interaction variables,

(1) both factors have a significant positive correlation with Percent Exam Points,

(2) both factors have a significant negative correlation with Attempts/Problem,

These correlations were also run with the quartiles of Content Pages Viewed as ReMATCH interaction variables in 2007; no statistically significant correlations were identified between the relevancy or accessibility and any of the dichotomous versions of these quartiles.

Discussion of Survey Responses to Interaction and Attitude Questions

Addressing Hypothesis Three required the determination of whether students who have more interactions with ReMATCH (logging into the system more, beginning it earlier in the semester, attempting more problems, spending more time solving each problem or viewing the tutorial pages, viewing more content pages, or attempting each problem multiple times) report more positive attitudes towards the intervention. Answering how the students felt about their interactions with ReMATCH was a critical step in the design and analysis and redesign of this web-based math and problem-solving tutorial. In order for any beneficial effects of an intervention to have a lasting positive impact on students, it needed to be well received by the students. It seemed logical to assume from the outset that students who had more interactions overall with ReMATCH would develop a more positive attitude about it through their continued use and growing familiarity with the tutorial; and, conversely, it also seemed logical that students who initially felt comfortable with the ReMATCH website and material would be likely to use it more. Determining whether these proposed associations existed between ReMATCH-use and more positive attitudes required the identification of variables that would serve as measures of student attitudes towards ReMATCH. The final survey for both years of the study contained a variety of questions related to how ReMATCH users responded the website content and its organization/presentation and how related they perceived the ReMATCH material to be to the course. Other questions on the final survey were included to obtain additional information to describe students' ReMATCH-use but which the ReMATCH website had not originally been designed to store.

Based on student survey responses to the multiple choice questions, it was discovered that for both years most students for whom ReMATCH was an assignment (~88%) began working on their ReMATCH assignments within the first two weeks of the course and that the middle 50% of the students in 2006 spent somewhere between 4 to 11 hours in all on the tutorial while 69% of the students in 2007, reported spending between 2 to 7 hours in all on the tutorial. It is interesting to note that when the tutorial was associated with the lectures, a much larger portion of students responded that most or all of the ReMATCH material was used in their general chemistry course. In order to obtain a robust measure of student attitudes towards ReMATCH, this measure of attitudes needed to be derived from more than a single survey question. On the final survey, there were 10 -11 Likert-scale questions related to the students use of the tutorial and reflections on these experiences. The combination of these questions into relevant *components* of the student attitudes towards ReMATCH presented the best opportunity for creating this robust measure. Therefore, separate factor analyses using principal component analysis were conducted using student responses to these questions from the final survey for each year. This analysis revealed the presences of two factors that can be thought of as contributing to student attitude to the tutorial: these were the relevancy factor and the

Table 57

		Bivariate Correlations			
		2006 Experimental		2007 ReMATCH$_{attempted}$ = 39-40	
		Relevancy Factor (n = 176)	Accessibility Factor(n = 179)	Relevancy Factor (n = 613)	Accessibility Factor (n = 624)
HSGPA	r	0.112	0.141	0.061	0.119**
	p	0.144	0.064	0.143	0.004
ACT$_{math}$	r	0.062	0.082	0.151**	0.190**
	p	0.427	0.292	0.000	0.000
ACT$_{composite}$	r	-0.025	0.030	0.077	0.139**
	p	0.745	0.700	0.066	0.001
Female	r	-0.063	-0.001	0.017	0.021
	p	0.401	0.991	0.665	0.591
African American	r	0.065	0.070	0.023	0.037
	p	0.389	0.346	0.569	0.352
Asian	r	0.025	-0.020	0.092*	0.023
	p	0.738	0.794	0.022	0.561
Hispanic	r	0.028	0.051	0.006	-0.011
	p	0.712	0.496	0.890	0.789
Caucasian	r	-0.082	-0.064	-0.086*	-0.019
	p	0.278	0.395	0.032	0.643
Other Ethnicity	r	0.041	0.043	0.025	-0.005
	p	0.582	0.563	0.529	0.901
Level$_{enrolled}$ = Fresh.	r	0.002	0.047	0.040	0.060
	p	0.983	0.532	0.324	0.134
Level$_{enrolled}$ = Soph.	r	0.060	0.009	-0.047	-0.057
	p	0.429	0.901	0.244	0.153
Level$_{enrolled}$ = Junior	r	-0.091	-0.068	-0.038	-0.050
	p	0.226	0.366	0.348	0.212
Level$_{enrolled}$ = Senior	r	-0.027	-0.053	0.075	0.064
	p	0.717	0.476	0.060	0.109
Status$_{entry}$ = Freshman	r	0.043	0.138	-0.063	-0.005
	p	0.571	0.063	0.115	0.902
Status$_{entry}$ = Transfer	r	-0.097	-0.209**	-0.003	-0.019
	p	0.198	0.005	0.945	0.643
Status$_{entry}$ = Other	r	0.105	0.123	.0970*	0.029
	p	0.163	0.098	0.016	0.476
Status$_{enrolled}$ = First Sem. Freshman	r	0.050	0.038	0.047	.0940*
	p	0.503	0.608	0.240	0.018
Status$_{enrolled}$ = First Sem. Transfer	r	-0.113	-0.166*	-0.003	0.028
	p	0.132	0.026	0.943	0.482
Status$_{enrolled}$ = Prior Freshman	r	0.100	0.092	-0.022	-.0870*
	p	0.182	0.216	0.586	0.029
Status$_{enrolled}$ = Prior Sophomore	r	0.048	0.078	-0.050	-0.075
	p	0.522	0.298	0.217	0.061
Status$_{enrolled}$ = Prior Jr. or Sr.	r	-0.158*	-0.121	0.006	-0.002
	p	0.034	0.105	0.873	0.963
Math$_{college}$ = None	r	0.038	0.081	0.072	0.107**
	p	0.611	0.281	0.073	0.007
Math$_{college}$= ColAlg/Trig/PreCalc	r	-0.058	-0.124	-0.116**	-0.119**
	p	0.438	0.095	0.004	0.003
Math$_{college}$ = Calc I	r	-0.004	-0.019	-0.015	-0.040
	p	0.961	0.800	0.706	0.312
Math$_{college}$ = Calc II and Above	r	0.036	0.090	0.072	0.056
	p	0.636	0.230	0.072	0.161

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 57 (continued)

Bivariate Correlations (continued)					
		2006 Experimental		**2007 ReMATCH$_{attempted}$ = 39-40**	
		Relevancy Factor (*n* = 176)	Accessibility Factor(*n* = 179)	Relevancy Factor (*n* = 176)	Accessibility Factor(*n* = 179)
ΔYears$_{entry}$	*r*	-0.073	-0.029	-0.060	-0.077
	p	0.331	0.699	0.132	0.055
Attendance Points	*r*	0.019	0.114	0.038	0.026
	p	0.803	0.126	0.350	0.517
Percent Exam Points	*r*	0.166*	0.133	0.150**	0.146**
	p	0.028	0.077	0.000	0.000
ReMATCH$_{attempted}$ = 5-28	*r*	-0.130	-0.191*	--	--
	p	0.084	0.011		
ReMATCH$_{attempted}$ = 29-38	*r*	-0.018	-0.011	--	--
	p	0.817	0.888		
ReMATCH$_{attempted}$ = 39-40	*r*	0.140	0.193**	--	--
	p	0.063	0.010		
ReMATCH Logins	*r*	0.097	0.132	0.039	-0.023
	p	0.198	0.079	0.334	0.564
Total Attempts	*r*	0.085	0.155*	-0.044	-0.045
	p	0.265	0.038	0.281	0.258
Attempts/Prob	*r*	0.012	0.066	-0.093*	-0.100*
	p	0.878	0.378	0.022	0.012
Content Pages Viewed = 0-10		--	--	0.060	0.046
				0.192	0.316
Content Pages Viewed = 11-		--	--	-0.063	-0.024
				0.171	0.601
Content Pages Viewed = -43		--	--	-0.016	0.006
				0.731	0.891
Content Pages Viewed = 44-88		--	--	0.022	-0.026
				0.637	0.566

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

accessibility factor. The combination of these factors in 2006 explained nearly 67% of the *attitude towards ReMATCH* item variances; and, in 2007, the two factors explained over 69% of the *attitude towards ReMATCH* item variances. For both years, the contribution from the relevancy factor (56 – 58%) was more than five times larger than the contribution from the accessibility factor (11%). Correlations between each of these factors and the demographic and academic background variables, as well as correlations between the factors and the ReMATCH interaction variables were calculated and examined for each year to determine if any significant differences existed between levels of ReMATCH use and student attitudes.

For the 2006 experimental group, the relevancy factor did not correlate significantly with any measures of student ReMATCH use. The accessibility factor had a significant negative correlation with ReMATCH$_{attempted}$ = 5-28 group and significant positive correlations with both the ReMATCH$_{attempted}$ =

39-40 group and with the interval-level variable measuring the total attempts at ReMATCH problems. Therefore, in the 2006 experimental group, it appears that only one aspect of student attitude, the weaker accessibility factor, is related to how much students interact with the tutorial and homework. However, it is promising to note that within this arrangement, better student attitudes towards ReMATCH – as measured by students' impressions that the website and content is accessible – are significantly correlated with measures of greater interaction with the ReMATCH website – as reflected by students attempting a greater number of unique ReMATCH problems and making a greater number of total attempts to solve the ReMATCH problems.

For the 2007 students who attempted 39-40 ReMATCH homework problems, both *attitudes towards ReMATCH* factors had many more significant correlations to student demographic and academic backgrounds. However, the relevancy and accessibility factors for each were significantly related to only one ReMATCH interaction variable: they were both negatively correlated with students making a greater number of attempts at each ReMATCH problem they try. This finding, at first, sounds as though it is contradicting the findings from the 2006 correlations; however, there is a difference in students making a greater number of total attempts to solve the ReMATCH problems (the significant variable in 2006) and in students making a greater number of attempts, on average, for *every* ReMATCH problem they try to solve (the significant variable in 2007). It is understandable that if students find the ReMATCH tutorial accessible they will be likely to attempt a greater number of problems which in turn will result in their having a greater number of total attempts at ReMATCH problems. Conversely, it is also easy to see how students having trouble early on with the ReMATCH homework may simply continue to work the same problems repeatedly because they do not understand how they could be wrong instead of seeking additional assistance with the issue. In such scenarios, a student may attribute their difficulty in obtaining the correct answer to a problem with the homework system not accepting their answer – thereby being inaccessible. Additionally, if they do not see the material in ReMATCH as relevant to their general chemistry course, it is likely that they are not actively engaging in their learning and really may not be able to see (or be trying to see) how they could deepen their understanding of chemistry.

It should be noted that most students with a very high attempts per problem rate are students who did not progress very far through the ReMATCH homework; they apparently got hung up on some problems early on and discontinued ReMATCH use. This finding in 2007 confirms the negative of Hypothesis Three – that students who get stumped on problems early on in the homework and do not continue to progress through the ReMATCH assignments are likely to have more negative attitudes regarding the accessibility and relevancy of ReMATCH. This supports the need to track the values of a variable for individual students so these problem students can be identified earlier and offered the assistance that they need sooner. This could be a very useful indicator of students in need of additional support in a general chemistry course.

The overall values for the relevancy and accessibility factors for both years, which all have average values below the neutral option of *neither* on the 5-point Likert-scale, suggest that despite the tutorial's focus on assisting students to develop many of the active learning and metacognitive skills necessary for the transfer of knowledge, the majority of the general chemistry students completing the final surveys each year do not see the relevancy of the tutorial to the course. Further research is necessary to determine the underlying causes of these feelings. It is promising, however, that student perception of the relevancy and accessibility of ReMATCH increases with increased student use of the system. Additional methods of engaging students in the active learning components of this system need to be investigated further.

Chapter 11

Conclusions, Implications, and Future Directions

Conclusions and Implications

The two-year implementation of ReMATCH in a traditionally arranged general chemistry classroom at the University of Kansas examined the impact of a designed intervention to assist students with the transfer of their mathematical knowledge to a chemistry context where it could be readily used for quantitative problem solving. The ReMATCH intervention was designed on constructivist-based pedagogies that focused on making the expert-processes of problem solving and of transferring knowledge across domains very explicit processes to the novice general chemistry student. These expert-processes were modeled in numerous ways through the ReMATCH tutorial pages and practice problems to encourage the students to begin modeling similar processes in their own tasks.

ReMATCH was introduced into the general chemistry course in the fall of 2006 at a time when the introductory lectures reviewing math-related chemistry topics were to be removed for the first time from the initial two weeks of the semester. To determine if ReMATCH could assist students with gaining a better understanding of and greater comfort with the topics beyond the level of understanding that students would obtain when covering this material all on their own (the self-study approach), the ReMATCH tutorial and homework assignments were implemented in a quasi-experimental design. To this end, the 40 question ReMATCH homework assignments were required for a grade in 14 of the 47 lab sections. In the fall of 2007, ReMATCH was implemented in the lecture of the same general chemistry course as a graded assignment for all students. These two implementations of ReMATCH resulted in very different student responses to the intervention. However, within both, evidence of the beneficial effect of sustained ReMATCH use were visible. In the 2006 study, students who attempted the full set of ReMATCH homework assignments were predicted to earn ~5% higher on their total exam points. The 2007 implementation of ReMATCH demonstrated that students who attempted all of the homework problems and visited at least half of the ReMATCH tutorial pages were predicted to earn ~8.5% higher on their total exam points compared to equivalent students performing fewer ReMATCH problems and viewing fewer ReMATCH tutorial pages.

In addition to ReMATCH being associated with higher exam performance in general chemistry, use of ReMATCH in 2006 was also demonstrated to result in increased confidence (as measured by *comfort-level*) with some of the introductory math-related chemistry topics which ReMATCH was designed to cover. In the 2007 implementation, when only the students who attempted all of the ReMATCH homework problems were considered, it became clear that individuals who were initially less confident in their math-related chemistry skills were more likely to view more of the ReMATCH tutorial pages. The students with lower than average initial comfort on these topics who viewed at least half of the ReMATCH tutorial pages were able to compensate for their initially lower levels of confidence so that on the final survey they were equally comfortable with most of the math-related chemistry topics. The analysis of student interactions with and perceptions of the ReMATCH website showed that student attitudes towards ReMATCH could be described by two factors: (1) how relevant and (2) how accessible they found the tutorial and homework to be. Students with more sustained interactions with ReMATCH presented more positive attitudes regarding the accessibility of the website in the 2006 study. The 2007 study of these factors elucidated the need to track students who have a large number of attempts per problem and a low number of total problems attempted, especially early in the semester, as these students are likely in need of additional assistance. If they continue in this pattern, they are likely to stop interacting with the intervention due to developing more negative relevancy and accessibility attitudes towards it.

The benefits that students recognized from their use of ReMATCH are attributable mainly to the underlying cognitive apprenticeship instructional model that the website attempted to provide for the students in an asynchronous fashion. At the same time, the successful implementation of ReMATCH across the two years of the general chemistry course is attributable to the *designed* nature of its development. Throughout the creation of ReMATCH, there were very clear goals guiding different decisions that were made about the composition, organization, and implementation of this intervention. Thanks to this framework, ReMATCH developed into a cohesive product that was relatively simple to introduce into a traditionally structured course as a methods of removing some of the review material from the beginning of the course lectures, allowing the lecture portion of the course to begin covering the more conceptually interesting aspects of the subject from the beginning of the semester.

According to Edelson (2002), design (-based) research can lead to three types of theories: (1) domain theories, (2) design frameworks, and (3) design methodologies. The research on ReMATCH presented in these studies extends theory in the following ways by contributing:

(1) the *ReMATCH design framework* describing the features required to support the transfer of implicit/tacit everyday mathematical abilities to explicit abilities performed (successfully) in a chemistry context and

(2) the (*asynchronous-)intervention classroom-integration framework* describing the features necessary to integrate an asynchronous-intervention successfully into a classroom setting with few changes to the course structure.

One outcome of this work is the model of the pedagogical framework on which this research was based. To achieve the goal of better transfer and confidence with chemical problem-solving among students in general chemistry, the model of the relationship between transfer and problem solving shown in Figure 1 was developed. It describes the connections that must be in place for transfer to occur and the impact of self-efficacy on the whole process. In further research, this model will be further refined. However, in its current state, it is an example of the type of *outcome theory* that Edelson (2002) identified as a one of two possible *domain theories* likely to develop from design-based research. It extends the constructivist theory on which it is based by illustrating points at which interventions can be applied to address the larger issue of improving students' problem-solving abilities in chemistry. ReMATCH addressed the transfer of math abilities to a chemistry context; however, there are many additional points illustrated in the model where other interventions could focus (and have previously focused).

A second outcome of these studies that developed directly from the design-based nature of the research was the creation of a design framework highlighting necessary components of any research on the integration of an asynchronous intervention into a lecture course. Edelson (2002) describes design frameworks as a second type of theory likely to develop from design-based research. Design frameworks "describe the characteristics that a designed artifact must have to achieve a particular set of goals in a particular context," (Edelson, 2002). The design framework that developed from this research describes the features required when using an asynchronous application to bring research-based practices into an existing course structure. Such an intervention must include the following features:

(1) A visible method of communication between stakeholders and the designer/researcher,
(2) A clear acknowledgement of the intervention's worth from the instructor of the course – such as assigning a grade for student use of the intervention,
(3) A structure to the intervention allowing it to function at multiple levels, fitting the current needs of its users, and
(4) A user-friendly interface - easy to navigate, tracks student progress, and has on-screen resources readily available.

According to Edelson, the benefits of design frameworks are two-fold: they clearly outline the design of interventions such that others can use it to develop tools for similar purposes in other contexts, and they allow researchers to build on the current understanding of what aspects of an intervention are critical to its integration or success (2002). Others have supported the benefits of clear design frameworks originating from design-based research when they have focused on the important role that context plays in this work and in its replication and extension by others (Wang & Hannafin, 2005). A greater understanding of how research-based practices can be successfully moved into a course is only possible if those researchers involved with design clearly identify their design frameworks.

Future

Research on the ReMATCH tutorial and homework system could take many directions in the future. Some of the first upgrades to the tutorial website that are planned for incorporation prior to the next implementation of ReMATCH include the following:

(1) the ability for ReMATCH to store data regarding each participants length of log-in sessions.
(2) the ability to provide multiple constants to a problem – adding variation to the problem sets to reduce specific problem familiarity.
(3) the provision of problem specific error assistance to increase mastery learning
(4) the ability to store all student responses to each problem.
(5) the inclusion of scaffolded examples in the homework sets.
(6) the addition of a web-based administrator view of student records.
(7) the improved integration of the ReMATCH homework problems with the traditional electronic homework sets.

There also remain a number of interesting questions that can be addressed with the previously collected data that was not included in these two studies. These analyses include (1) a detailed comparison of the specific ReMATCH tutorial pages that were viewed by most students or commonly viewed multiple times by the same students. This comparison has as its goal the determination of which aspects of particular pages in the tutorial made them appeal more to the students and (2) an in depth examination of the qualitative data that was also collected in the open-ended response questions from the final surveys for both years. In addition to these, a separate qualitative analysis of how students determine their methods of interacting with web-based resources (including the ReMATCH tutorial) would provide necessary insight into the development of more engaging learning resources.

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Appendix A

Survey for General Chemistry Students in Fall 2005

Circle the choice below that applies to each statement.

Previous Math and Science Experiences		**1 2**
1	I took a chemistry course in high school.	Yes / No
2	I got a grade of B or better in my previous chemistry course(s).	Yes / No
3	I had more than one year of chemistry in high school.	Yes / No
4	I had algebra II in high school.	Yes / No
5	I had trigonometry in high school.	Yes / No
6	I had pre-calculus in high school.	Yes / No
7	I had calculus in high school.	Yes / No
8	I had physics in high school.	Yes / No
9	I have taken or am enrolled in college algebra in college.	Yes / No
10	I have taken or am enrolled in calculus in college.	Yes / No
11	I have taken or am enrolled in physics in college.	Yes / No
12	I have taken or am enrolled in engineering courses in college.	Yes / No

13 I plan to major in the following field: *Check the box next to your desired major. Mark* ***only one*** *box.*

☐ Chemistry	☐ Chemical & Petroleum Engineering	☐ Civil Engineering
☐ Electrical Engineering	☐ Mechanical Engineering	☐ Aerospace Engineering
☐ Computer Science	☐ Biology (any)	☐ Environmental Studies
☐ Geology	☐ Geography	☐ Physics
☐ Mathematics	☐ English	☐ Communication
☐ History	☐ American Studies	☐ African & African American Studies
☐ Women's Studies	☐ Psychology	☐ Exercise Science
☐ Education (any)	☐ Foreign Language (any)	☐ Business
☐ Economics	☐ Architecture	☐ Fine Arts (any)
☐ Film Studies	☐ Other	

14 Which of the following courses are you planning to take? *Check the box next to each course that you plan to take.*

☐ General Chemistry II	☐ Organic Chemistry I	☐ Organic Chemistry II
☐ Analytical Chemistry	☐ Physical Chemistry	☐ Inorganic Chemistry
☐ Other		

This Semester in Chemistry							
	Circle the value below that most accurately indicates your reaction to each statement.						
		Never	Very Rarely	Rarely	Occasion-ally	Fre-quently	Always
15	I always write down my units when I work a chemistry problem.	1	2	3	4	5	6
16	I have good problem solving skills.	1	2	3	4	5	6
17	I feel comfortable with the concept of a *mole* in chemistry.	1	2	3	4	5	6
18	I can convert from *mass* to *moles* of a compound.	1	2	3	4	5	6
19	I can convert from *density* to *moles* of a compound.	1	2	3	4	5	6
		Never	Very Rarely	Rarely	Occasion-ally	Fre-quently	Always
20	I have struggled with *unit conversions* this semester.	1	2	3	4	5	6
21	I struggled with the rules for *significant figures*.	1	2	3	4	5	6
22	I struggled with *stoichiometry* concepts this semester.	1	2	3	4	5	6
23	I struggled with the *gas law* concepts.	1	2	3	4	5	6
24	I struggled with *mole fractions* this semester.	1	2	3	4	5	6
25	I struggled with the *thermodynamics* concepts.	1	2	3	4	5	6
26	I would be interested in a web-based math tutorial to accompany this course.	1	2	3	4	5	6
27	I would be interested in a web-based problem solving tutorial for this course.	1	2	3	4	5	6
28	I would be interested in personal math tutoring for this course.	1	2	3	4	5	6
29	I was interested at the beginning of the semester when we were reviewing math concepts (such as unit conversions, significant figures, and the metric system).	1	2	3	4	5	6

This Semester in Chemistry (Continued)

Circle the value below that most accurately indicates your reaction to each statement.

		Disagree Strongly	Disagree Moderately	Disagree Slightly	Agree Slightly	Agree Moderately	Agree Strongly
30	I find this course interesting when we cover chemistry concepts.	1	2	3	4	5	6
31	I find this course interesting when we cover problem solving concepts.	1	2	3	4	5	6
32	I would attend class more if fewer math concepts were	1	2	3	4	5	6
33	I would attend class more if the lecture focused more on the chemical concepts at the theoretical level.	1	2	3	4	5	6

Appendix B

Initial Survey for Fall 2006 and 2007 General Chemistry Students

1. Please check the box below after reading the information statement if you wish to participate in this study.

   Information Statement:

   The Department of Chemistry at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You should be aware that even if you agree to participate, you are free to withdraw at any time without penalty.

   We are conducting this study to better understand the effects of making a web-based math tutorial available in the CHEM184 course. This will entail your completion of an initial questionnaire attached to this document and a final questionnaire made available near the end of the semester about your use of the web-based math tutorial and your experiences in the course. Both questionnaires are expected to take approximately 15 minutes to complete. The information from these questionnaires will not be shared with the professor of the course.

   The content of the questionnaires should cause no more discomfort than you would experience in your everyday life. Although participation may not benefit you directly, we believe that the information obtained from this study will help us gain a better understanding of what knowledge students have when entering CHEM184, how students use the tutorial in the course, and how the use of the tutorial affects student performance in the course and student attitude about the course. Your participation in the questionnaires and the use of your data is solicited, although strictly voluntary. Your name will not be associated in any way with the research findings. Although your KUID will be used to link your use of the tutorial with information obtained from the Office of Institutional Research and Planning, any research findings will be written up in the aggregate--no individual data will be reported. If you would like additional information concerning this study before or after it is completed, please feel free to contact us by phone, mail, or e-mail.

Completion of the following questionnaire indicates your willingness to participate in this project and that you are over the age of eighteen. If you have any additional questions about your rights as a research participant, you may call (785) 864-7429 or (785) 864-7385 or write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7563, email dhann@ku.edu or mdenning@ku.edu.

Sincerely,

M. Danielle Barker	Joseph A. Heppert, Ph.D.
Principal Investigator	Faculty Supervisor
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(2006 version) Approved by the Human Subjects Committee University of Kansas, Lawrence Campus (HSCL). Approval expires one year from 8/15/2006.

(2007 version) Approved by the Human Subjects Committee University of Kansas, Lawrence Campus (HSCL). Approval expires one year from 8/15/2007.

☐ Yes, I have read the Information Statement and agree to participate in the study.

2. What is your age?

3. What is your race?

 American Indian or Alaskan Native Asian or Pacific Islander

 Black (African American), not of Hispanic Origin Hispanic

 White (Caucasian), not of Hispanic Origin Other

4. What is your gender?

 Male Female

5. Are you enrolled as an in-state or out-of-state student?

 in-state student out-of-state student

6. What is (are) your intended major(s)?

(*2006 version*) Mark all that apply.

(*2007 version*) (a) Mark only the **ONE** field from the list provided that you consider to be your primary major by clicking the box next to it. If you have not decided on a major yet, please select "UNDECIDED At This Time" at the bottom of the list.

 1. Accounting

 2. Aerospace Engineering

 3. African & African-American Studies

 4. American Studies

 5. Anthropology

 6. Architectural Engineering

 7. Architectural Studies

 8. Architecture

- ☐ 9. Art & Design
- ☐ 10. Astronomy
- ☐ 11. Atmospheric Science
- ☐ 12. Biochemistry
- ☐ 13. Biology
- ☐ 14. Business Administration
- ☐ 15. Chemical Engineering
- ☐ 16. Chemistry
- ☐ 17. Civil Engineering
- ☐ 18. Classical Antiquity
- ☐ 19. Classical Languages
- ☐ 20. Communication Studies
- ☐ 21. Computer Engineering
- ☐ 22. Dance
- ☐ 23. East Asian Languages & Cultures
- ☐ 24. Economics
- ☐ 25. Electrical Engineering
- ☐ 26. Engineering Physics
- ☐ 27. English
- ☐ 28. Environmental Studies

- ☐ 29. European Studies
- ☐ 30. French
- ☐ 31. Geography
- ☐ 32. Geology
- ☐ 33. Germanic Languages & Literatures
- ☐ 34. Health, Sport, & Exercise Sciences
- ☐ 35. History
- ☐ 36. History of Art
- ☐ 37. Human Biology
- ☐ 38. Human Development
- ☐ 39. Humanities
- ☐ 40. International Studies
- ☐ 41. Journalism
- ☐ 42. Latin American Studies
- ☐ 43. Linguistics
- ☐ 44. Literature, Language, & Writing
- ☐ 45. Mathematics
- ☐ 46. Mechanical Engineering
- ☐ 47. Microbiology
- ☐ 48. Music

☐ 49. Music Theory

☐ 50. Music Performance

☐ 51. Music Education & Music Therapy

☐ 52. Nursing

☐ 53. Petroleum Engineering

☐ 54. Pharmacy

☐ 55. Philosophy

☐ 56. Physics

☐ 57. Political Science

☐ 58. Prelaw Study

☐ 59. Premedical Professions

☐ 60. Psychology

☐ 61. Public Administration

☐ 62. Religious Studies

☐ 63. Russian & East European Studies

☐ 64. Slavic Languages & Literature

☐ 65. Social Work

☐ 66. Sociology

☐ 67. Spanish

☐ 68. Speech-Language-Hearing

- 69. Teaching & Leadership (elementary, middle, or secondary)
- 70. Theater & Film
- 71. Visual Arts Education
- 72. Women's Studies
- 73. Other Major--Not Listed
- 74. *(2007 version)* UNDECIDED At This Time

(*2007 version*) (b) You may list in the boxes below other majors/minors that you plan to obtain by typing into the boxes the number listed next to that major in the list above.

2nd Major

(If you do not have a 2nd major or a minor, please type 999 in this field.)

3rd Major

(If you do not have a 3rd major or a minor, please type 999 in this field.)

4th Major

(If you do not have a 4th major or a minor, please type 999 in this field.)

7. Prior to this course, I have taken the following math classes. Mark all that apply.

- Algebra II in High School
- Pre-Calculus in High School
- Calculus in High School
- Algebra in College
- Calculus I in College
- Calculus II in College

8. Prior to this course, I have taken the following science classes. Mark all that apply.

- ☐ Chemistry in High School
- ☐ Physics in High School
- ☐ Engineering in High School
- ☐ Chemistry in College
- ☐ Physics in College
- ☐ Engineering in College

9. Prior to this course, which of the following topics have you worked with before? Mark all that apply.

- ☐ Conversion Factors
- ☐ Metric Units (grams, meters, etc.)
- ☐ Scientific Notation
- ☐ Significant Figures
- ☐ Mole (Avogadro's Number)
- ☐ Molar Mass
- ☐ Percent Composition by Mass
- ☐ Empirical Formula
- ☐ Limiting Reactant
- ☐ Theoretical Yield
- ☐ Percent Yield
- ☐ Molarity

For questions 10-18, please select the description that best indicates your level of agreement with each of the following statements about your **current** level of comfort with specific concepts.

10. I feel comfortable with the concept of the mole in chemistry.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

11. I feel comfortable using significant figures.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

12. I feel comfortable using scientific notation.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

13. I feel comfortable using rounding rules.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

14. I feel comfortable converting between metric units.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

15. I feel comfortable converting between grams and moles.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

16. I feel comfortable with the concept of limiting reactants.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

17. I feel comfortable with the concept of theoretical yield.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

18. I feel comfortable with the concept of the mole in chemistry.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

19. (*2007 version*) What is your **current** level in college?

- Freshman
- Sophomore
- Junior
- Senior

20. (*2007 version*) I have already started working on the ReMATCH Math Tutorial Assignments for this course.

- Yes, I have started the Math Tutorial Assignments.
- No, I have NOT started the Math Tutorial Assignments.
- I do not know what the Math Tutorial Assignments are.

21. (*2007 version*) Have you attended every lecture for this course? If not, how many have you missed?

- Yes, I have attended every lecture for this course this semester.
- I have missed 1 lecture.
- I have missed 2 lectures.
- I have missed 3 lectures.
- I have missed 4 lectures.
- I have missed 5 lectures.
- I have missed more than 5 lectures.

22. (*2007 version*) If you have already started the ReMATCH Math Tutorial Assignments, have you sought help with any of the questions on the assignments?

- Yes, I have asked the designer of the site for assistance.
- Yes, I have attended a discussion section for assistance.
- Yes, I have emailed the TAs for this course for assistance.
- No, I have not sought help because I have not needed it.
- No, I have not sought help with the ReMATCH Math Tutorial Assignments, but I have had problems on these assignments that I could not answer correctly.
- I have NOT started working on the ReMATCH Math Tutorial Assignments for this course.

Appendix C

Final Survey for Fall 2006 and 2007 General Chemistry Students

1. What is (are) your intended major(s)?

(*2006 version*) Mark all that apply.

(*2007 version*) (a) Mark only the **ONE** field from the list provided that you consider to be your primary major by clicking the box next to it. If you have not decided on a major yet, please select "UNDECIDED At This Time" at the bottom of the list.

- ☐ 1. Accounting
- ☐ 2. Aerospace Engineering
- ☐ 3. African & African-American Studies
- ☐ 4. American Studies
- ☐ 5. Anthropology
- ☐ 6. Architectural Engineering
- ☐ 7. Architectural Studies
- ☐ 8. Architecture
- ☐ 9. Art & Design
- ☐ 10. Astronomy
- ☐ 11. Atmospheric Science
- ☐ 12. Biochemistry
- ☐ 13. Biology
- ☐ 14. Business Administration
- ☐ 15. Chemical Engineering

- [ ] 16. Chemistry
- [ ] 17. Civil Engineering
- [ ] 18. Classical Antiquity
- [ ] 19. Classical Languages
- [ ] 20. Communication Studies
- [ ] 21. Computer Engineering
- [ ] 22. Dance
- [ ] 23. East Asian Languages & Cultures
- [ ] 24. Economics
- [ ] 25. Electrical Engineering
- [ ] 26. Engineering Physics
- [ ] 27. English
- [ ] 28. Environmental Studies
- [ ] 29. European Studies
- [ ] 30. French
- [ ] 31. Geography
- [ ] 32. Geology
- [ ] 33. Germanic Languages & Literatures
- [ ] 34. Health, Sport, & Exercise Sciences
- [ ] 35. History

- [ ] 36. History of Art
- [ ] 37. Human Biology
- [ ] 38. Human Development
- [ ] 39. Humanities
- [ ] 40. International Studies
- [ ] 41. Journalism
- [ ] 42. Latin American Studies
- [ ] 43. Linguistics
- [ ] 44. Literature, Language, & Writing
- [ ] 45. Mathematics
- [ ] 46. Mechanical Engineering
- [ ] 47. Microbiology
- [ ] 48. Music
- [ ] 49. Music Theory
- [ ] 50. Music Performance
- [ ] 51. Music Education & Music Therapy
- [ ] 52. Nursing
- [ ] 53. Petroleum Engineering
- [ ] 54. Pharmacy
- [ ] 55. Philosophy

- ☐ 56. Physics
- ☐ 57. Political Science
- ☐ 58. Prelaw Study
- ☐ 59. Premedical Professions
- ☐ 60. Psychology
- ☐ 61. Public Administration
- ☐ 62. Religious Studies
- ☐ 63. Russian & East European Studies
- ☐ 64. Slavic Languages & Literature
- ☐ 65. Social Work
- ☐ 66. Sociology
- ☐ 67. Spanish
- ☐ 68. Speech-Language-Hearing
- ☐ 69. Teaching & Leadership (elementary, middle, or secondary)
- ☐ 70. Theater & Film
- ☐ 71. Visual Arts Education
- ☐ 72. Women's Studies
- ☐ 73. Other Major--Not Listed
- ☐ 74. *(2007 version)* Undecided at this time

(*2007 version*) (b) You may list in the boxes below other majors/minors that you plan to obtain by typing into the boxes the number listed next to that major in the list above.

2nd Major [ ]

(If you do not have a 2nd major or a minor, please type 999 in this field.)

3rd Major [ ]

(If you do not have a 3rd major or a minor, please type 999 in this field.)

4th Major [ ]

(If you do not have a 4th major or a minor, please type 999 in this field.)

2. (*2007 version*) What is your **current** level in college?

- Freshman
- Sophomore
- Junior
- Senior

For questions 3-11, please select the description that best indicates your level of agreement with each of the following statements about your **current** level of comfort with specific concepts.

3. I feel comfortable with the concept of the mole in chemistry.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

4. I feel comfortable using significant figures.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

5. I feel comfortable using scientific notation.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

6. I feel comfortable using rounding rules.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

7. I feel comfortable converting between metric units.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

8. (*2006 version*) I feel comfortable converting between grams and moles.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

9. I feel comfortable with the concept of limiting reactants.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

10. I feel comfortable with the concept of theoretical yield.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I do not remember this topic

11. I feel comfortable with the concept of molarity.

- ☐ Strongly Agree
- ☐ Inclined to Agree
- ☐ Neither
- ☐ Inclined to Disagree
- ☐ Strongly Disagree
- ☐ I do not remember this topic

12. What skills do you feel you should have developed more fully before taking this course? Mark all that apply.

- ☐ Algebra skills
- ☐ (*2006 version*) Logarithm skills
- ☐ Problem solving skills
- ☐ Reading skills
- ☐ Science writing skills
- ☐ Skills for setting up solutions to word problems
- ☐ Skills to aid in understanding word problems
- ☐ Skills to reduce careless mistakes
- ☐ Skills for coping with test anxiety
- ☐ (*2006 version*) Nothing
- ☐ Other (If you mark this option, please list these other skills in the field below.)

13. Mark all of the following that you used regularly when seeking assistance with this course.

(*2006 Version*)

- My TA during my lab section
- A discussion section
- A TA holding office hours
- Emailing the super TAs
- The professor's office hours
- A chemistry tutor
- A friend who has taken the course previously
- A friend currently taking the course with you
- The internet
- The ReMATCH tutorials
- The solutions manual for the
- I did not regularly seek assistance for this course.

Please list in the space below any other sources you regularly used for assistance in this course.

(*2007 Version*)

- My lab TA during my lab section or his/her office hours/discussion sections
- Another lab TA or super TA via the course email or during office hours/discussion sections
- The professor during his office hours or via email
- A chemistry tutor or a friend who has taken the course previously
- A friend currently taking the course with you
- The solutions manual for the course textbook
- The ReMATCH tutorials
- Other internet sites related to chemistry or math

Please list the names of any of these websites that you used regularly and/or found particularly helpful.

Please list in the space below any other resources you regularly used for assistance in the course.

14. (*2007 version*) Have you attended every lecture for this course? If not, how many have you missed?

- Yes, I have attended every lecture for this course this semester.
- I have missed 1 lecture.
- I have missed 2 lectures.
- I have missed 3 lectures.
- I have missed 4 lectures.
- I have missed 5 lectures.
- I have missed more than 5 lectures.

15. What was your favorite aspect of this general chemistry course?

16. What was your least favorite aspect of this general chemistry course?

17. Which of the following changes do you think would improve this course? Mark all that apply.

- [ ] Making attendance at lecture a part of the course grade
- [ ] Requiring attendance for discussion sections
- [ ] Requiring attendance at problem-solving workshops for ALL students

  (These workshops are not currently offered.)
- [ ] (*2007 version*) Requiring attendance at problem-solving workshops for students with a 25 or below on the math component of the ACT. (These workshops are not currently offered.)
- [ ] (*2006 version*) Requiring use of a web-based math tutorial
- [ ] More time to take exams
- [ ] Exams that require you to show your work (NOT multiple-choice exams)
- [ ] Time spent covering problem-solving during your laboratory section

Please record any other suggestions for improvements to this course in the field below.

18. (*2007 version*) Did you seek help with any of the questions on the Math Tutorial Assignments that were part of ReMATCH?

- ☐ Yes, I emailed the designer of the site for assistance with questions on the Math Tutorial Assignments.
- ☐ Yes, I attended a discussion section for assistance with questions on the Math Tutorial Assignments.
- ☐ Yes, I emailed the TAs for the course for assistance with questions on the Math Tutorial Assignments.
- ☐ No, I did NOT seek help for any questions on the Math Tutorial Assignments because I did NOT need any assistance to complete the assignments.
- ☐ No, I did NOT seek help for any questions on the Math Tutorial Assignments, but I did have problems on these assignments that I could not answer.
- ☐ No, I did NOT attempt any of the Math Tutorial Assignments for general chemistry that were part of ReMATCH.

19. My overall experience with ReMATCH and the Math Tutorial Assignments was good.

- ☐ Strongly Agree
- ☐ Inclined to Agree
- ☐ Neither
- ☐ Inclined to Disagree
- ☐ Strongly Disagree
- ☐ I did not use the ReMATCH tutorials and/or attempt the Math Tutorial Assignments.

20. I found the ReMATCH tutorials to be easy to read.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I did not use the ReMATCH tutorials.

21. I found the language used in the ReMATCH tutorials easy to understand.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I did not use the ReMATCH tutorials.

22. I found the ReMATCH tutorial website easy to navigate.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I did not use the ReMATCH tutorials.

23. The ReMATCH tutorials and Math Tutorial Assignments covered topics that were stressed in class.

- ☐ Strongly Agree
- ☐ Inclined to Agree
- ☐ Neither
- ☐ Inclined to Disagree
- ☐ Strongly Disagree
- ☐ I did not use the ReMATCH tutorials and/or attempt the Math Tutorial Assignments.

24. I feel the ReMATCH tutorials aided my understanding of the material in the course.

- ☐ Strongly Agree
- ☐ Inclined to Agree
- ☐ Neither
- ☐ Inclined to Disagree
- ☐ Strongly Disagree
- ☐ I did not use the ReMATCH tutorials.

25. The ReMATCH tutorials provided me with additional information on some of the material that was necessary for this general chemistry course.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I did not use the ReMATCH tutorials.

26. I found the material in the ReMATCH tutorials and Math Tutorial Assignments applicable to the course exams.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I did not use the ReMATCH tutorials and/or attempt the Math Tutorial Assignments.

27. I found the everyday examples and practice problems given in the ReMATCH tutorial pages beneficial to my understanding of the chemistry concepts.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I did not use the ReMATCH tutorials.

28. I usually attempted to work the example problems in the ReMATCH tutorials before looking at their solutions.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I did not use the ReMATCH tutorials.

29. I found the explanations given for the different topics in the ReMATCH tutorials helpful.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I did not use the ReMATCH tutorials.

30. I feel that using ReMATCH was worth my time.

- Strongly Agree
- Inclined to Agree
- Neither
- Inclined to Disagree
- Strongly Disagree
- I did not use the ReMATCH tutorials and/or attempt the Math Tutorial Assignments.

31. When did you start to use the ReMATCH tutorials and/or attempt the Math Tutorial Assignments?

(*2006 version*)

- ☐ The week it was announced in class
- ☐ The week it was announced in lab
- ☐ Before the 1st exam
- ☐ Between the 1st exam and the 2nd exam
- ☐ After the 2nd exam
- ☐ Never

(*2007 version*)

- ☐ Immediately after it was announced in class (during the 1st full week of class)
- ☐ Before the 1st Math Tutorial Assignment was due (during the 2nd week of class)
- ☐ After one or more of the Math Tutorial Assignments were due but before the last Assignment was due
- ☐ A day or two before the 1st exam
- ☐ Between the 1st exam and the 2nd exam
- ☐ After the 2nd exam
- ☐ Never

32. Approximately how much time in all did you spend using the ReMATCH tutorial and/or Math Tutorial Assignments?

(*2006 version*)

- 1 hour
- 3 hours
- 5 hours
- 10 hours
- 15 hours
- 20+ hours
- None

(*2007 version*)

- 1 – 2 hours total (average of 15 – 30 minutes/assignment)
- 2 – 4 hours total (average of 30 – 45 minutes/assignment)
- 4 – 7 hours total (average of 1 – 2 hours/assignment)
- 8 – 11 hours total (average of 2 – 3 hours/assignment)
- 12 – 15 hours total (average of 3 – 4 hours/assignment)
- 16 – 19 hours total (average of 4 – 5 hours/assignment)
- 20 – 23 hours total (average of 5 – 6 hours/assignment)
- 24 – 28 hours total (average of 6 – 7 hours/assignment)
- 29 or more hours total (average of 7 or more hours/assignment)
- None because I did not use ReMATCH and/or attempt the Math Tutorial Assignments

33. I think the ReMATCH tutorials should…

- ☐ cover less material.
- ☐ stay the same.
- ☐ cover more material.
- ☐ I did not use the ReMATCH tutorials.

34. How much of the material covered in the ReMATCH tutorials did you use in your general chemistry course this semester?

- ☐ All of it
- ☐ Most of it
- ☐ Some of it
- ☐ None of it
- ☐ I did not use the ReMATCH tutorials.

35. (*2007 version*) Did you refer to the tutorial sections of ReMATCH for assistance with questions **OTHER** than those in the Math Tutorial Assignments? Mark all that apply.

- ☐ Yes, I referred to the tutorial sections of ReMATCH when attempting some WebAssign homework questions.
- ☐ Yes, I referred to the tutorial sections of ReMATCH when attempting some questions from the review tests in the back of the textbook.
- ☐ Yes, I referred to the tutorial sections of ReMATCH when studying for Exam 1.
- ☐ Yes, I referred to the tutorial sections of ReMATCH when studying for Exam 2.
- ☐ Yes, I referred to the tutorial sections of ReMATCH when studying for Exam 3.
- ☐ Yes, I referred to the tutorial sections of ReMATCH when studying for Exam 4.
- ☐ Yes, I referred to the tutorial sections of ReMATCH when studying for the Final Exam.
- ☐ Yes, I referred to the tutorial sections of ReMATCH when working on assignments for my chemistry lab section (pre-labs or lab reports).
- ☐ No, I ONLY referred to the tutorial sections of ReMATCH when attempting the Math Tutorial Assignments.
- ☐ No, I NEVER referred to the tutorial sections of ReMATCH during this course.

36. What was your favorite aspect of the ReMATCH tutorials?

37. What was your least favorite aspect of the ReMATCH tutorials?

38. What would you like to see added to the ReMATCH tutorials?

39. What would you like to see removed from (changed about) the ReMATCH tutorials?

40. What additional math concepts would you like to see the ReMATCH tutorials cover?

41. Do you think that the ReMATCH tutorials should be a mandatory part of the general chemistry class for all students? Please state why or why not.