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Math and Chemistry Connections

Angela Goodhart

Honors Project
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Abstract:

The connection between mathematics skills and chemistry course success was examined by analyzing data from Assessment and Learning in Knowledge Spaces (ALEKS) software initial assessment for CHEM 1250, General Chemistry I, and final course grades from fall of 2009 and 2011. These years were chosen to evaluate the effect of a mathematics prerequisite of MATH 1220, College Algebra II. In 2011, after the prerequisite was in place, students had mastered significantly more of the mathematics topics on the initial ALEKS assessment, but there was not a significant change in final course grade.

Introduction:

A strong foundation of mathematics skills would seem to point toward improved performance with chemistry. While the reasons behind this cannot be measured absolutely, it seems clear that the link between math fluency and chemistry ability is founded in some similarities between the fields. It would seem likely that chemistry success requires not only science knowledge, but also a solid foundation of mathematical skills and a logical method of thinking. Therefore, it seems reasonable that the stronger the mathematics background an individual possesses, the greater the likelihood of meeting success with chemistry.

It is natural to assume that prior knowledge of topics has a positive effect on performance in related areas. Dochy, Segers, and Buehl’s 1999 review of prior knowledge found that despite variation in degree, prior knowledge is in fact a strong predictor of the learning outcome, especially concerning “procedural metacognitive knowledge,” or the ability to know and understand what to do. This can be applied to the connection between math and chemistry, as many chemistry topics involve mathematical concepts; therefore, previous exposure to these basic math concepts should increase one’s ability to apply the concept to the context of a chemistry problem. In another sense, Moscovic and Newton argue in their article “Math and Science: A Natural Connection?” that it is indeed only natural to integrate middle childhood math and science education because similar problem solving skills are developed in both subject areas, and these same problem solving skills will be used across disciplines later in life. Singer also calls for integration of STEM fields at the undergraduate level, arguing that the lines between the fields are becoming increasingly blurry as the 21st century progresses. Moreover, in a Chemistry Self-efficacy study, it was found that the only significant difference between majors’ and non-majors’ self-efficacy was related to ability to perform everyday chemistry tasks; the two groups were statistically identical in cognitive and psychomotor skill self-efficacy, suggesting that students from other fields believe that the ability to perform well in chemistry comes from an application of knowledge gained elsewhere.

Connections can be found across a variety of STEM fields; Partin, Haney, Worch, Underwood, Nurnberger-Haag, Scheurmann, and Midden found that math attitude was a major determinant in undergraduate introductory Biology performance, along with self-efficacy and test anxiety. However, when Louis and Mistele examined the role of gender and self-efficacy in regards to both mathematics and four specific science fields (biology, chemistry, earth science, and physics) at the eighth grade level, they found that significant differences in each gender’s performance and self-efficacy existed across the
fields, so that although math and all science fields are closely related, there are distinct differences amongst them. This means that the connection between math self-efficacy and biology found in Partin, Haney, Worch, Underwood, Nurnberger-Haag, Scheurmann, and Midden’s study cannot be assumed to apply to mathematics and chemistry; math self-efficacy may or may not be as strong (or a stronger) an indicator of chemistry performance as chemistry self-efficacy. These results indicate the importance of considering specific links between mathematics and each science when integrating the fields at any level.

The existing sources exploring the connection specifically between mathematics and chemistry indicate that chemistry mastery can be linked to well-developed mathematics skills. Fisher found that both multiple choice pre-calculus and performance based mathematics tests predicted students’ performance in algebra, hard science calculus, social science calculus, and chemistry. Leopold and Edgar established that students’ ability to perform well on questions requiring basic mathematics skills including logarithms, scientific notation, and graphs accounted for 17% of their final course grade in the second semester of general chemistry. At more advanced levels, specifically upper division physical chemistry undergraduate courses for majors and graduate courses, the connection persists; according to the Journal of Chemical Education’s article “Critical Thinking in Chemistry Using Symbolic Math Documents,” using programs like Mathematica and Mathcad, which explain more complex calculus than is typically used, for the exploration of chemistry fosters higher order cognitive skills and allows for a more thorough understanding of the chemistry topic involved. Furthermore, Potgieter, Harding, and Engelbrecht attempted to determine if students’ struggles with chemistry problems involving strong mathematical bases stemmed from the application of the mathematics to the chemistry context or a lack of solid mathematical foundations; the results of the study suggested overwhelmingly that the difficulties encountered arose from a poor understanding of the mathematical background involved, not the transfer to the chemistry context.

Contrastingly, students who participated in the MATCH Program, which combined preparatory chemistry (pre-general chemistry) and intermediate algebra into one course and covered more material, mainly by paralleling topics between the two subjects (e.g. learning about logarithms in algebra and reinforcing the concepts with applications to pH in chemistry) had higher final grades in chemistry than the control group (which took the two courses separately) but lower mathematics grades. This suggests that while the students in the program had a better understanding of the chemistry from the integration of the courses, the combination of courses seemed to be detrimental to their mathematics performance, suggesting that their understanding of chemistry did not stem from a more thorough understanding of the mathematics. Another study, designed to adapt a Process-oriented guided inquiry learning (POGIL) process from mathematics to a physical chemistry course, while highly successful in its overall adaptation, still had some further questions left unanswered, such as how to fully adapt the structure of the mathematics course to the material covered in physical chemistry in a way to promote the a stimulating discussion of the physical chemistry topics, which allows students to gain the best possible understanding of the material.

Perhaps some of the crucial differences between mathematics and chemistry can be explained by Breen and Lindsay’s motivation study, which looked at the factors that motivate students across eight different
disciplines. The study found that several different factors, including confidence in success, interest in the field, and analytic academic goals, motivate those studying different fields. Each field that can be associated with mathematics and science (computing, biology, geology, and food and nutrition science) had a different composition of motivational factors compared to one another, suggesting that what motivates students in specific fields may contribute to their overall success. For example, the strongest motivating factor for biology students was found to be enjoyment from “thinking about getting grades back,” while for students studying food science and nutrition the strongest motivating factor measured was that “academic activities are a source of enjoyment.” This can account for some of the crucial differences in the extent to which students who specifically study chemistry learn chemistry versus the extent to which they learn mathematics.

In “Mathematics Education and Common Sense,” Keitel and Kilpatrick define common sense as “practical good sense gained by experience of life, not by special study” and advocate that it provides a “counterbalance to specialization,” which is needed in mathematics to develop well-rounded problem solving skills. That is, it is important not only to know how to do a certain specific problem using a particular method (as is generally the case with mathematics problems), but also to be able to recognize new types of problems that can be solved using the same method or based on related concepts (e.g., knowing to factor a polynomial when asked to find the zeroes of a polynomial). Going further, it can be said common sense in this setting applies in other problem solving situations, so this need for the ability to make sense of the world from experiences can be linked to nonmathematical courses; Langenfeld and Pajares’s validation of the Math Self-efficacy Scale recognizes the application of common sense and the ability to solve problems to areas outside of mathematics. The validation consists of two components: mathematics courses themselves and non-mathematics courses which need math, such as chemistry. Indeed, Tassoobshiraz and Glynn found that chemistry problem conceptualization is a significant predictor of problem strategy, and problem strategy was in turn a strong predictor of problem solutions. Problem conceptualization is the result of applying common sense and chemistry knowledge to a problem, so the need for common sense in chemistry as well as mathematics becomes apparent.

Finally, in “Mathematics Worth Knowing, Resources Worth Growing, Research Worth Noting: A Response to the National Mathematics Advisory Panel Report,” the authors praise the report for identifying that it is necessary to integrate the concepts and procedures within mathematics education and critique the report for not considering the factors contributing to math competency in combination with one another. These factors include teacher competency in the subject area, technology used, and instructional approaches employed, as well as the combination of algebra mastered in Algebra I and Algebra II. It is reasonable to think these suggestions apply to the chemical field as well. First, in that it is necessary to integrate mathematical concepts to achieve high performance in a chemistry course, and second, to consider the combinations of factors affecting overall course performance as not necessarily independent of one another.

ALEKS, which stands for "Assessment and LEarning in Knowledge Spaces," is an educational software program designed around Knowledge Space Theory, a mathematical cognitive science which measures individuals’ knowledge bases in terms of what they have mastered and what they are ready to learn.
Knowledge space theory consists of a complex mathematical language used to delineate between concepts and divide a subject area into distinct topics, or basic concepts of the subject. The unique combination of mastery of these topics leads to a multitude of possible knowledge states for individuals. A University of California, Irvine team of software engineers, cognitive scientists and mathematicians developed the ALEKS software based upon these knowledge states.

ALEKS uses adaptive assessments based on the knowledge structure to measure students’ knowledge in relatively short assessments of approximately 25-30 questions. This is done based on a hierarchy within the topics, suggesting that topic A mastery is required in order to gain mastery of some related topic B. For example, if a student misses a question on topic A, it is assumed that the student has not mastered topic B either, and therefore a question on topic B does not need to be presented. After a brief tutorial to train the students with the program, students complete an initial assessment. The program can then measure the students’ knowledge in two forms using the assessment and hierarchy of topics: all topics mastered by a student (known as the knowledge space) are determined by the assessment and topics that are ready to be learned based upon what a student does know (referred to as the outer fringe of the knowledge state) are determined based on the hierarchy of topics. When using the ALEKS software, the student can see these topics arranged in a pie, the shading of which indicates how many of the topics within a particular “slice,” or related group of topics, have been mastered. Each slice will display the ready to learn topics when clicked on. Students can then select a ready to learn topic and enter learning mode, which provides specific questions within a topic that a student must complete correctly a certain number of times in a row (which varies depending upon the number of incorrect attempts) in order to gain mastery. The questions also include an “explain” option to teach students how to do new problems. As students master new topics, more ready to learn topics become available, according to the hierarchy of the topics determined by the software. Additionally, to ensure long term mastery, the program can give additional assessments at random intervals, which will reset both the mastered topics and “ready to learn” topics based on students’ performance.

Using this same structure, the ALEKS software has been applied to a multitude of subject areas at all grade levels, specifically mathematics, general chemistry, and mathematics preparation for physics at the undergraduate science level.

The purpose of this study is to examine ALEKS data from two general chemistry courses in order to determine the effect, if any, of a mathematics prerequisite for the course. The courses examined were CHEM 1250, General Chemistry I, from the fall of 2009 and 2011. A mathematics prerequisite of MATH 1220, College Algebra II, was put in place between these years. ALEKS data based on the initial ALEKS assessment was used to predict whether students’ mathematics knowledge and overall course grade improved after the prerequisite was in place. Based on the findings of Leopold and Edgar specifically, in which mathematics skills were shown to be linked to chemistry course grade, it is expected that the mathematics prerequisite should not only increase students’ mastery of mathematics topics, but an increased mathematics base should increase overall course grades. Furthermore, as Potgieter, Harding, and Engelbrecht found, it appears that the difficulties students encounter with chemistry problems rooted in mathematics stems from a lack of understanding of the mathematics skills, not the application to a chemistry context, so improving students mathematics backgrounds should improve their ability to
solve mathematics-related chemistry problems (eg. stoichiometric calculations, thermochemistry, and ideal gas law problems). Ideally, the mathematics prerequisite should, first of all increase students’ knowledge of mathematics, and second of all, improve their overall performance in the course as a result of the increased mathematics skills.

Methods:

The ALEKS data examined consists of the initial assessment information for all students in two CHEM 1250: General Chemistry courses, from Fall 2009 and Fall 2011. The 2009 class consisted of 179 students who both completed an initial ALEKS assessment and finished the course without withdrawing. The 2011 class consisted of 214 students who both completed an initial ALEKS assessment and finished the course without withdrawing. The data analysis was carried out using data only from those students who completed the course for a grade. The data sets include a list of all ALEKS topics in the course, including several mathematics topics as well as chemistry topics, and whether each student answered correctly or else answered incorrectly or was not asked the question on the initial assessment. Correct answers are denoted by a “1” and assumed “mastered” by the ALEKS program; all other topics are assumed not mastered and denoted by a “0.” Additionally, final course grades for each student were available. Grades for four different fall CHEM 1250 courses were available, from 2009-2012, to provide a frame of reference for any changes in course grade. This was necessary in case either of the years examined (2009 and 2011) had an unusual grade distribution that would not allow for an accurate comparison (eg. If 2009 had uncharacteristically high grades compared to other years or 2011 had uncharacteristically low grades compared to other years).

Beginning in Fall 2010, a course prerequisite for CHEM 1250 of MATH 1220: College Algebra II was implemented. The two data sets allowed the effects of this prerequisite on initial knowledge (as assessed by ALEKS) and final course grade to be examined.

The number of students who demonstrated mastery of each topic on the initial ALEKS assessment was totaled for both data sets in Microsoft Excel.

All topics classified by ALEKS as arithmetic or algebra were considered mathematics topics, and the total numbers of arithmetic, algebra, and combined arithmetic and algebra topics answered correctly were calculated for each student. These results were used to make a histogram for each year. The totals for algebra (19 topics total), arithmetic (11 topics total), and combined algebra and arithmetic (30 topics total) were then compared between years. A two sided t-test assuming unequal variances was performed to compare the differences in the total number of mathematics topics mastered between years. This analysis was repeated on both algebra and arithmetic topics separately from the combined total.

Next, final course grade was examined by converting letter grades to a quantitative four point scale and removing withdrawals from the data series. Histograms of final course grade were prepared for both 2009 and 2011 and then combined into one graph by percentage. A two-sided equal variances t-test was also carried out to determine if a significant difference between course grades existed.
Scatter plots of final course grade versus the number of mathematics topics mastered as measured by the initial ALEKS assessment were prepared for each data set in order to look for a link between mathematics mastery and chemistry success. An initial plot was prepared with a linear trend line fit to the data. A second plot was then prepared by adding a random number from -0.25 to 0.25 to the course grade in order to better show the quantity of grades corresponding to each number of mathematics topics.

Finally, 95% confidence intervals were then constructed for the lines of best fit in Figures 14 and 16 using Matlab in order to determine if the slope of the lines was nonzero.

**Results and Discussion:**

The histograms of the total number of mathematics topics mastered on the initial ALEKS assessment are shown in Figures 1 and 2. When the number of students is converted to a percentage in order to take into account small differences in class size, the results in Figure 3 are obtained.

![Histogram of Mathematics Topic Mastery](image)

**Figure 1.** The distribution of mathematics topic mastery in 2009 shows that a majority of the students had already mastered between 16 and 26 topics.
Figure 2. The distribution of mathematics topic mastery in 2011 shows that a majority of the students had already mastered between 18 and 26 topics.

Figure 3. The percentage of students who had initially mastered 19-27 mathematics topics increased in 2011 compared to 2009.

Upon examination of Figure 3, it certainly appears that on the whole students knew more mathematics topics in 2011 than in 2009, as the number who had mastered 19-24 topics increased by at least 50% and the number who knew only between 0 and 16 topics for most values. Although the number of
students who knew 27-28 of the 30 topics declined, the decrease is smaller than the increase in students who increased the number of mastered mathematics topics. This would make sense, since in 2011 all students were required to have taken College Algebra II prior to beginning the General Chemistry course, and therefore should be expected to have better mathematics skills than previously, such as in 2009. The one-sided t-test carried out in Table 1 supports the claim that the number of mathematics topics students have already mastered is significantly different at the 95% level: the t-value of 2.95 is greater than the critical value of 1.65, so it is unlikely the observed difference is the result of chance. The p-value of 0.0017 means that the increase in number of mathematics topics mastered on the initial ALEKS assessment would only be observed by chance 0.17% of the time.

Table 1. According to the one-tailed t-test at the 95% confidence level, the difference between the number of mathematics topics students mastered in 2009 and 2011 is statistically significant.

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>19.2</td>
<td>20.8</td>
</tr>
<tr>
<td>Variance</td>
<td>37.6</td>
<td>18.0</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>6.1</td>
<td>4.2</td>
</tr>
<tr>
<td>Observations</td>
<td>182</td>
<td>215</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>degrees of freedom</td>
<td>314</td>
<td></td>
</tr>
<tr>
<td>t Statistic</td>
<td>2.95</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.0017</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail (0.05 level)</td>
<td>1.65</td>
<td></td>
</tr>
</tbody>
</table>

When the subset of mathematics topics that are classified by ALEKS as algebra topics was analyzed the results were very similar to mathematics topics as a whole; the number of algebra topics students had mastered increased between 2009 and 2011. This increase was found to be statistically significant at the 95% level. This is also to be expected, since the mathematics prerequisite was an algebra course, which would have required students to have learned algebra related topics.
Figure 4. The mastery of algebra topics in 2009 shows no specific trends and a large variance.

Figure 5. The mastery of algebra topics in 2011 shows a majority of student knew between 9 and 15 of the 19 topics.
Figure 6. Students appear to have initially mastered more algebra topics in 2011 than in 2009.

Table 2. According to the one-tailed t-test at the 95% confidence level, the difference between the number of algebra topics students mastered in 2009 and 2011 is statistically significant.

### t-Test: Two-Sample Assuming Unequal Variances

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>9.9</td>
<td>11.3</td>
</tr>
<tr>
<td>Variance</td>
<td>18.5</td>
<td>9.2</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>4.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Observations</td>
<td>179</td>
<td>214</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>degrees of freedom</td>
<td>311</td>
<td></td>
</tr>
<tr>
<td>t Statistic</td>
<td>3.71</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.00012</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail (0.05 level)</td>
<td>1.65</td>
<td></td>
</tr>
</tbody>
</table>
When a similar analysis was carried out on the mathematics topics classified as arithmetic, the difference did not seem to be quite as large between 2009 and 2011. In fact, in 2011 a lower percentage of students knew 10-11 of the 11 arithmetic topics, although a larger percentage knew 9 of the topics in 2011, as Figure 9 shows. One noteworthy observation is that on both cases, a majority of the students knew most of the arithmetic topics, so this would not have much room for improvement. The t-test (both two-tailed and one-tailed for arithmetic topics) yields a t value less than the critical t value, showing that the changes are not significant at the 95% level.

Figure 7. Most students had mastered at least 10 of the arithmetic topics in 2009.

Figure 8. Most students had mastered at least 9 of the arithmetic topics in 2011.
Table 3. According to the two-tailed t-test at the 95% confidence level, the difference between the number of arithmetic topics students mastered in 2009 and 2011 is not statistically significant.

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>9.6</td>
<td>9.4</td>
</tr>
<tr>
<td>Variance</td>
<td>3.1</td>
<td>2.7</td>
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<tr>
<td>Standard Deviation</td>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Observations</td>
<td>179</td>
<td>214</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>degrees of freedom</td>
<td>368</td>
<td></td>
</tr>
<tr>
<td>t Statistic</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.65</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>1.97</td>
<td></td>
</tr>
</tbody>
</table>

It seems that while algebra topic mastery was significantly different between 2009 and 2011, arithmetic topic mastery was not. The overall mathematics topic mastery was improved between years, but this cannot necessarily be attributed to the implementation of a mathematics prerequisite; other factors could account for this change. For example, the prerequisite could require students to wait a year...
before taking General Chemistry, and therefore have a year of added college experience that could have affected their effort level on the initial assessment. It is also impossible to determine if the ALEKS software changed at all, which could have changed the hierarchy of topics and presented mathematics topics in the initial assessment more or less frequently. Additionally, if the topic hierarchy did not change but the actual mathematical questions posed did, the difficulty level of the questions could have changed; it is possible the mathematics questions were made easier to understand by 2011, and therefore more students were able to answer them correctly.

After examining the differences in students’ scores on mathematics questions between 2009 and 2011, the difference in grades was examined between 2009 and 2011 using the bar graphs shown in Figures 10, 11, and 12. The 2009 grade distribution is slightly skewed, while the 2011 grade distribution is more strongly skewed; the most notable change is that while the most common grade in 2009 was a C, in 2011 the most common grade was a B, as seen in Figure 12. However, the average grade for 2011 was still a C. When the percentages of each grade are compared between the years, the most prominent difference is that in 2011 there are fewer C’s and more B’s. However, the F’s and D’s increase slightly and the A’s decrease slightly. The average grade actually stayed about the same between the two years, and when a two-tailed t-test (assuming equal variances, since the variances are the same) was used, the differences were not found to be significant at the 95% level.

![Figure 10. The 2009 grade distribution is slightly skewed.](image1)

![Figure 11. The 2011 grade distribution is more strongly skewed.](image2)
Figure 12. A noticeably higher percentage of students received B’s in 2011 than in 2009, but the average grade is about the same.

Table 4. The two-sided t-test of course grades was not significant.

### t-Test: Two-Sample Assuming Equal Variances

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Variance</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Observations</td>
<td>179</td>
<td>214</td>
</tr>
<tr>
<td>Pooled Variance</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>degrees of freedom</td>
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<td></td>
</tr>
<tr>
<td>t Statistic</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>1.97</td>
<td></td>
</tr>
</tbody>
</table>

The final course grades for CHEM 1250 from Fall 2009, Fall 2010, Fall 2011, and Fall 2012 were examined in order to determine if any great changes occurred between years. The results show that the grade distribution is somewhat symmetric for all years (with the exception of the large number of B’s in 2011), with some minor fluctuations from year to year, most notable in the number of students who receive a grade of “A.”
The course grades were calculated on a 90/80/70/60 scale with a small drop in scale of 1-3% depending upon how each distribution turned out, so they were not statistically adjusted to a curve. In 2009, 20% of the final course grade was based on ALEKS completion, and in 2011 16% of the final course grade was based on ALEKS completion. However, this small difference should not greatly impact the grade; furthermore, ALEKS completion refers to topics mastered in learning mode and is not necessarily connected to the initial assessment.

When the relationship between initial mathematics topic mastery and CHEM 1250 course grade was examined by plotting course grade against the number of mastered mathematics topics for each student, in neither 2009 nor 2011 did a strong trend emerge. In both cases, the scatter plot has very little linear relationship present, with an $R^2$ value of just 0.1 in 2009, and only 0.06 in 2011. Nevertheless, a slight positive effect of number of mathematics topics on final course grade due to the positive slope of the line is observed, despite the much larger contribution of other factors. In 2009, approximately 12% of the variability is explained by the number of initially mastered mathematics topics, while in 2011, only approximately 5.7% of the variability can be explained by the number of initially mastered mathematics topics. This could mean that the students in 2011, after the implementation of the mathematics prerequisite, were more homogeneous when they entered the course than the students in 2011.

One observable feature is that while students who had correctly answered a number of mathematics topics received grades covering the full range, students failing to initially answer 9 or more mathematics questions correctly did not receive a grade higher than C in 2009, and those failing to answer 13 or more correctly did not achieve a grade higher than C in 2011. This suggests that while knowing a large percentage of the mathematics topics did not make a student more likely to succeed, not knowing a majority of the mathematics topics did make a student less likely to succeed.
Figure 14. This is a graph of 2009 course grade (converted to quality points; F=0, D=1, C=2, B=3, A=4) plotted against the total number of mathematics topics correct with each data point representing one student. The equation of the line of best fit is $y = 0.0742x + 0.8382$ with an $R^2$ value of 0.12.

Figure 15. This is a graph of 2009 course grade (converted to quality points and with a random value added to spread out the points) plotted against the total number of mathematics topics correct. Each data point represents one student.
Figure 16. This is a graph of 2011 course grade (converted to quality points; F=0, D=1, C=2, B=3, A=4) plotted against the total number of mathematics topics correct with each data point representing one student. The equation of the line of best fit is $y = 0.073x + 0.7338$ with an $R^2$ value of 0.058.

Figure 17. This is a graph of 2011 course grade (converted to quality points and with a random value added to spread out the points) plotted against the total number of mathematics topics correct. Each data point represents one student.

However, looking again at Figure 12, there was a considerable increase in the number of students who received B’s between 2009 and 2011. Examining the percentage of students who received either an A or a B in 2009 compared to 2011, 43.4% of students received an A or a B in 2009, while 48.2% received these grades in 2011. So, while the average grade remained about the same, and the percentage of students receiving a grade of C or higher actually decreased slightly within the two year gap, the percentage of students who received a grade of B or higher increased. This suggests that course grades did improve for students, in that students who would normally receive a passing grade of C may have
earned a grade of B instead. While this data has not proved statistically significant, it does show an improvement that may be worth further study.

When a confidence interval was constructed for the line of best fit through the plots of course grade versus number of mathematics topics initially mastered for 2009 and 2011 using Matlab, both intervals did not include zero, and we conclude that the slopes are nonzero at the 95% confidence level. For 2009, the 95% confidence interval for the slope is (0.0442, 0.1043). For 2011, the 95% confidence interval for the slope is (0.0332, 0.1129). The fact that the slopes are nonzero for both lines suggests that for both year, the number of mathematics topics correct on the initial ALEKS assessment does have a positive relationship to final course grade, although a small one.

**Conclusion:**

This study suggests that students taking CHEM 1250 (General Chemistry I) after the enactment of a mathematics prerequisite of MATH 1220 (College Algebra II) did in fact have more knowledge of ALEKS mathematics topics initially, particularly topics classified as “algebra” topics. However, the data examined do not support the claim that this increased mathematics knowledge significantly raised course grades overall, although it is important to remember that not all factors could be controlled for. Nevertheless, certain trends suggest reason for further study of the connection between mathematics knowledge and chemistry course grade. Furthermore, it is possible that although chemistry course grades remained about the same between 2009 and 2011 despite an increase in initially mastered mathematics topics, the mathematics knowledge students had prior to the General Chemistry may have allowed them to understand certain chemistry topics more quickly and easily, although the overall effect was not to raise their grade. It may be interesting to determine if a connection between other measures of mathematics abilities and chemistry success can be found.

Course grade has a number of determining factors to consider, making it quite complex. Factors such as test taking ability and laboratory work (which is component of the course grade) may heavily influence the final course grade. For example, if students understand the chemistry better as a result of the mathematics prerequisite but perform poorly on exams despite understanding the concepts (due to test anxiety or simply being a poor test taker) or do not understand applications of theory to laboratory procedures, their final course grades will not reflect their understanding of theoretical chemistry material. In fact, final course grade may not be a fair assessment of the level of understanding students have gained of the material, making it necessary to redefine chemistry “success” as measured by a standard other than final course grade, or a combination of measures in addition to course grade.

Finally, in any further investigations, it is necessary to keep in mind the important role of individual student motivations. While the motivation level could in fact be increased or decreased by prior mathematics knowledge (increased because students may feel more confident, decreased because students may believe they do not need to work hard since they already know mathematics), it is important to realize that individual students are driven by a variety of factors, and the implementation of the mathematics prerequisite may not impact these factors enough to lead to noticeable change.
With that being said, student motivation, which is difficult to measure and variable, may play a role in course grade that outweighs other factors enough to make predictions of chemistry course success based on mathematics background at all quite a challenge.

References:


This review of literature on prior knowledge was designed to bring together past research in order to evaluate the effect of prior knowledge on learning. For the purposes of the study, prior knowledge was defined as knowledge that is available before a certain learning task, structured, declarative, and procedural, partly explicit and partly inferred, and dynamic in nature. While variation in testing techniques and what was being measured as prior knowledge undoubtedly led to different degrees of importance of prior knowledge, it was found that prior knowledge of related topics has a relatively important impact on students’ performance overall. Some common trends observed were that a prior knowledge pretest was a significant predictor of post-test performance; prior knowledge was the most significant predictor of performance in several causal modal studies; and the correlation between prior knowledge and procedural metacognitive knowledge.


This article suggests that integrating mathematics and science education at the middle school level can help answer the question commonly posed by students of “When are we ever going to need this?” It points out that as it becomes more important to emphasize problem solving skills in both math and science, integration, to one degree or another, is only natural. The authors admit that integration is not easy; they include a timeline of math and science related activities engaged in dating back to 1981. In the authors’ point of view, part of the difficulty comes from educators’ and professionals’ desires to either view science merely as a context for math or math as simply a tool for science, neither of which is the structure advocated by the authors. Rather, they recommend a framework in which each field stands on its own with collaboration between the two, an equal give and take system.


This article evaluates the need for integration of science, technology, engineering, and mathematics fields, specifically at the undergraduate level. The demand for professionals in STEM fields who are fluent across the STEM fields as well as in depth in their specific area is ever more apparent as the 21st century progresses. The critical pivot between high school and higher education is analyzed, including the reform of Advanced Placement courses in high schools, which all too often evaluate breadth but not depth of a topic and fail to draw connections across fields. In this day and age, the lines between fields have become exceptionally blurry, and many studies see a need for the increased integration and cooperation of the STEM fields. The need for more collaborative learning is also emphasized. However, while the need for integration and collaboration has been recognized, changes in the education system have not been prevalent for
a variety of reasons, the primary explanation supplied by the author being a lack of willingness to integrate on the part of faculty, administration, and disciplinarian societies.


This two phase study explained the development and validation of the College Chemistry Self-Efficacy Scale (CCSS). The first phase was administered to 363 college freshmen enrolled in General Chemistry at a university in Turkey. The second phase was administered to 353 college freshmen from the same university, enrolled in the same General Chemistry course. The administered questionnaire was designed to measure students’ attitudes toward chemistry and their beliefs about their abilities, with possible responses consisting of a range from 1-9 ranking how well students felt they could perform the specific task, 1 being “very poorly” and 9 being “very well.” Each item on the questionnaire could be considered related to self-efficacy for cognitive skills (the mental abilities used to think, study, and learn), psychomotor skills (tasks performed requiring muscle skills, such as setting up laboratory apparatus), or everyday application. As predicted, a significant difference between majors and non-majors was observed in a univariate analysis of the questionnaire data, but only in the area of performing everyday chemistry tasks; while majors scored higher in both cognitive and psychomotor skills, the differences were not significant. The study also discusses the applications of the result to chemistry education in order to increase student success.


Three hundred eighteen non-major biology undergraduates were given surveys measuring biology and mathematics attitudes, self-efficacy, intrinsic motivation, extrinsic motivation, task value, control of learning beliefs, and test anxiety in order to correlate each of these factors to course performance. Which factors themselves best predicted self-efficacy were also examined. The results found that the only significant determinants of course performance were self-efficacy, test anxiety, and math attitude. However, biology attitudes, control of learning beliefs, test anxiety, intrinsic goal orientation, task value, and extrinsic goal orientation were all found to be linked to self-efficacy itself. Considerations to apply the results to design a more motivating biology learning environment are discussed.


This study used the *Trends in International Mathematics and Science Study 2007* eighth grade data to evaluate connections between achievement, gender, and self-efficacy in math and science. The authors point out that both math and science involve numbers, critical thinking and problem solving. The study found that males demonstrate a significantly higher self-efficacy for mathematics, but not performance (females out performed males in algebra), while there is no significant gender difference in science self-efficacy, but males outperformed females
specifically in three of the four subject areas: Biology, Earth Science, and Physics (there was no significant difference in chemistry performance). While the study focuses primarily on gender differences, it also discusses differences in trends in mathematics as compared to science fields.


This thesis describes the process of studying the predictability of course grades in first quarter algebra, calculus for the hard sciences, calculus for the social sciences, and chemistry using diagnostic tests. An exam composed of two parts, a multiple choice algebra diagnostics test (ADT) and a performance-based test was administered to 1033 students at the University of California, Santa Barbara. The exam results were correlated with final course grades in each of the four courses. It was found that the performance based test had a significant correlation with each final grade, the ADT had an even greater correlation to each course, and the combination of the two tests proved to have the greatest statistical significance when relating it to course grade. The thesis also discusses many topics in which math and chemistry are specifically correlated.


This study correlated success in a second semester General Chemistry course to students’ performance on a 20-question, 30-minute, calculator free mathematics fluency test developed by the University of Minnesota. The multiple choice test covered mathematical topics relevant for second semester chemistry such as logarithms, scientific notation, graphs, and other basic algebra components. The test was administered to 325 students across different degree granting programs at the University of Minnesota enrolled in the second semester of General Chemistry, and the students did not study for the test prior to its administration. Twelve of the 20 questions were found to have a significant correlation to final course grade, and when taken as a subset, the correlation coefficient between the twelve question subset and final course grade was 0.41, which is significant for the sample of 325. However, the coefficient of determination, 0.17, indicates that only 17% of the students’ performance can be predicted based on their score on the math test. The relationship was especially strong amongst the high and low extremes. The study also discusses potential pedagogical misconceptions that lead to students’ lack of understanding in mathematics, including the assumptions that: students “already know the simple material,” students who don’t understand are simply “bad at math,” and students are not taking the chemistry course to learn math. Other interesting results include that a) while many of the students were familiar with log properties, they had forgotten the actual meaning of the log itself; b) despite performing well on scientific notation questions, students appear to be less than comfortable with directly interpreting and performing operations with scientific notation, as many converted numbers to standard form and back
again to perform the operations; c) forty percent of the students could use a review of problems involving “ratios of numbers with integer exponents” without chemical applications, as only 60% of the students correctly answered items 17 and 18, dealing with rates problems based on chemical kinetics.


This article describes new Mathcad and Mathematica documents relating to chemistry, justifying their use as necessary to develop higher order cognitive skills for students in advanced courses such as physical chemistry. The symbolic math documents are said to contribute to a learning environment in which students can grow their reasoning and thinking skills, in order to learn justified and believable knowledge. The documents described relate to areas of chemistry including hybrid orbitals and molecular geometry, ionized hydrogen molecule wavefunctions, numerical methods and chemical kinetics, and heat, work, and entropy at the molecular level. All of the symbolic math documents tend to explain more complex mathematical principles than are generally involved in the teaching of individual chemistry concepts to allow for a fuller level of understanding and increase the students’ capacity to think critically within and across the realms of the topics.


This study is based on the assumption that undergraduate chemistry students encounter difficulty in mastering topics with a strong mathematical basis, and was designed to determine whether the difficulty is due to students’ mathematical foundations or the “complexity introduced by transfer of mathematics to a new scientific domain.” The study administered a question based on the Nernst equation in two different forms: one consisting of the actual Nernst equation \( E = E^o - \frac{RT}{nF} \ln Q \) and one using conceptually equivalent mathematical terminology but containing no scientific context. The former was randomly administered to 36 students, while the latter was randomly given to 41. The students had taken three semesters of calculus as well as linear algebra and differential equation, and had completed three modules of chemistry, two at the first year level in general and organic and one in organic at the second year level; they were enrolled in analytical chemistry (their fourth module) during data collection. No significant differences were found between the test forms, although all around students proved to understand the basic algebra applications of the question, while struggling with the graphing application, which involved graphing the function and identifying the intercepts. The results suggest that the difficulties encountered in understanding chemistry with a strong mathematical basis results more from a lack of a developed math background than any confusion when the scientific context is applied to the concepts.

This article describes the development and framework of the MATCH program, which is a course designed to combine preparatory chemistry (pre-general chemistry) and intermediate algebra. The initial trial course included 72 students and was designed to reinforce overlapping concepts in algebra and chemistry by drawing connections and increasing exposure. The combination of the courses also allowed more material to be covered throughout the course of the semester than in separately taught courses, since similar topics were taught in an overlapping manner. The MATCH program was compared to a control group, an equivalent preparatory chemistry class, to evaluate its effectiveness, in which both groups were given a pre and posttest, and it was found that the MATCH program’s students had grades higher on average in the area of chemistry, but lower in mathematics. However, not all students in the control group were also enrolled in an intermediate algebra course, so the control students could have already taken the math course and improved their skills in mathematics relative to the MATCH group. The control group also had a better attitude toward mathematics than the MATCH group, which again could be attributed to the fact that students in the control group may have already completed the equivalent intermediate algebra course. According to the survey questions in the tests, MATCH students were more willing to work together and ask questions, but they also found the material more challenging (although the denser content of their course could account for this). The evaluation of the two groups’ attitudes toward chemistry showed them to be statistically the same.


This paper takes past educational studies in mathematics used to create a teaching methodology and adapts them to a chemistry classroom, specifically a physical chemistry course. Process-oriented guided inquiry learning (POGIL) is utilized as an instructional approach within a physical chemistry classroom, and the response of students to the method is considered to be engaging. However, some inconsistencies and areas for further study exist, such as how to relate the POGIL system to the structure of materials and lead to the best discourse for learning. The study also notes distinct variations in the extent to which students engaged in the discourse and how well they learned material from day to day.


This study analyzed differences in motivational factors across eight different fields of study: biology, history, computing, planning, anthropology, geology, food science and nutrition, and education. The review provides explanations of several motivational theories, such as trait theories versus context specific theories. A questionnaire was developed and used by the researchers to evaluate the motivation of all students participating in the study. While the study found that students in different disciplines are in fact motivated by different factors, the results of a single study are acknowledged as not conclusive enough to generalize to all students. However, recognizing the fact that differences may exist provides crucial groundwork for tackling challenges to universities such as drop rates. The individual results were analyzed in many ways, but some similarities exist between computing and the science based fields, such as students holding “analytic academic goals.”
This chapter examines the relationship between common sense and mathematics. Common sense is most nearly defined as the ability to make sense of the world or explain things, usually referring to everyday knowledge. Mathematics and common sense are both based upon “abstraction from social action based on shared sense experiences, social experiences, and social intentions,” but the emphasis in each area has developed differently. After reviewing existing research related to either measuring common sense, evaluating mathematics education, or a combination of the two, the authors conclude that common sense complements school mathematics, but it is not usually considered a concept of mathematics education, which should be changed. The authors also stress that common sense is not a level of mastery and serves as “a counterbalance to specialization.” The final suggestion of the chapter to emphasize and refer to common sense in mathematics education is considered a means to create a more powerful knowledge base.

This study gave 522 undergraduates a 52-question modified Mathematics Self-efficacy Scale (MSES) test, which consisted of three parts: solution of mathematics problems, completion of mathematics tasks used in everyday life, and performance in college courses requiring knowledge and mastery of mathematics. After receiving the results, five “factors” affecting mathematics self-efficacy were created, and each question associated with a factor. Students were then administered the 18-question Mathematics Problems Performance Scale, which asked students to solve questions relating to the self efficacy questions. The effectiveness of the MSES was evaluated by determining whether the test seemed to measure a common underlying construct when each factor was analyzed individually, meaning if each of the five factors show a relationship to the overall score of the students on the MPPS, which they did. It was also found that the course self-efficacy scale is composed of two main factors: mathematics courses themselves and non-mathematics courses that require math. The importance of the context of the survey is also emphasized.

This study was based on Adaptive Control of Thought-Rational (ACT-R) theory and focused on formulating and testing a model of expertise in chemistry problem solving with quantitative, well-defined problems. One hundred and one introductory chemistry science majors answered questions relating to chemistry self-efficacy, problem conceptualization tasks, and actual chemistry problems. For the latter two sections, students were asked to explain their reasoning,
so that their strategy could also be scored. Problem conceptualization was evaluated by asking students to classify problems as stoichiometry, thermochemistry, or properties of solutions problems without solving the problems, while problem strategy was evaluated by having the students solve quantitative problems. Significant correlations observed included a link between problem conceptualization and problem strategy as well as a relationship between self-efficacy and problem strategy, meaning that problem strategy scores increased in response to both conceptualization and self-efficacy scores increasing. Problem strategy was also correlated with the problem solutions, and it was observed that students who approached the problems with a working-forward thinking strategy tended to perform better than those who approached them with a working-backward strategy. The implications of this study as a chemistry expertise model are discussed as to how each factor affects students’ strategies and success.


In this review of the National Mathematics Advisory Panel Report, the emphasis on the content of mathematics courses is appreciated while three major areas are critiqued. First, the authors criticize the strict definition of Algebra I and Algebra II courses studied; they would prefer the panel to have evaluated a less limited focus on algebra education and its applications as a whole. Next, the authors would suggest the evaluation of factors affecting mathematical teaching (such as teachers' content knowledge, classroom technologies, and instructional approaches) in combination with each other, rather than as isolated variables. The final complaint lodged against the report is that the evaluators worked in groups divided into those with similar knowledge and expertise in each area, not allowing connections between each groups’ findings to flow as freely. The article provides the background of how the authors arrived at these critiques and offers ideas to correct the inadequacies of the report, as well as suggestions of new research questions that could be asked.


This website explains the development of ALEKS software, which is educational software based upon Knowledge Space Theory, using a complex mathematical language. This language delineates between concepts and divides a subject area into distinct topics. The unique combination of mastery of these topics leads to a multitude of possible knowledge states for individuals. The ALEKS software measures an individual’s competence in two forms: all topics mastered by the individual (known as the knowledge space) and topics that are ready to be learned based upon what the individual does know (referred to as the outer fringe of the knowledge state). In these ways, the ALEKS software has been applied to a multitude of subject areas at all grade levels, specifically mathematics, general chemistry, and mathematics preparation for physics at the undergraduate science level.