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High School Chemistry Content Background of Introductory College Chemistry Students and Its Association with College Chemistry Grades

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The first college chemistry course plays an important role in the academic trajectory of college students, with many counseled to enroll in fulfillment of general science requirements. What chemistry content should incoming students know best before taking their first course? How high school chemistry teachers respond to this question will directly affect their teaching. Choosing which topics deserve the most time and which require less is an important decision. In this study, we will explore the connection between success in introductory college chemistry and high school chemistry content coverage.

Many researchers have studied connections between college chemistry success and student background experiences such as SAT–Math scores *(1–3),* mathematical ability *(2–4),* mathematics coursework *(3),* chemistry background *(5–7),* and placement tests *(7–9).* Educational research on chemistry has long held an interest in finding best practice in high school chemistry for college chemistry preparation *(10).* Though helpful for student placement in college chemistry, these findings provided limited guidance for high school curriculum decisions on course content. To provide insight into the connection between high school content and college performance, we address the following research questions:

> What content do introductory college chemistry students report emphasizing in their high school courses? How do regular, honors, and Advanced Placement (AP) HS chemistry courses compare in terms of content emphasis?
>
> What high school chemistry content is significantly associated with success in introductory college chemistry controlling for students' demographic and general educational backgrounds?

Methodology

The data used in this manuscript come from a study started in 2002. *Factors Influencing College Science Success* (Project FICSS, NSF-REC 0115649) is a four-year nationally representative study funded through the Interagency Educational Research Initiative and administered by the National Science Foundation (NSF). Project FICSS surveyed college students engaged in introductory science coursework across three disciplines: biology, chemistry, and physics. The students completing the surveys came from more than 100 introductory college science courses at four-year colleges and universities across the United States.

This study analyzed the chemistry subsample collected from 38 first-semester introductory college chemistry courses taught at 31 four-year colleges and universities in fall 2002 and fall 2003.[1] We compared participating and nonparticipating schools across measures such as school size, admissions selectivity, or geographic location and found no results indicating bias based on self-selection. The 20 public schools and 11 private schools are located in 22 states. The sampled schools covered the entire range of four-year institutions and ranged from small liberal arts colleges with less than 2500 undergraduates to large state universities with more than 10,000 undergraduates. For the purpose of continuity, we chose to include only courses with large lecture-based classes, smaller recitation sections, and laboratory sessions.[2] Surveys were administered during class sessions, (i.e., lectures, recitation meetings, or lab sessions). The college professors later entered the students' final course grades on the surveys before returning them to the researchers. Though designed to be individually unidentifiable, a survey question asked whether the responding student would agree to be contacted through email, approximately 25% of the students volunteered email addresses. The responses from the emails were used as a means of providing limited corroboration of our findings. The final chemistry subsample contained 3521 student surveys.

Given the size and scope of the study, the survey instrument covered a large number of curricular issues in high school chemistry. Included in the surveys were questions about the quantity of time students recalled spending on particular content topics.[3] Questionnaire development included feedback from college professors and high school teachers, field testing with introductory college chemistry students, and interviews with student focus groups. Background information explaining the purpose and eventual use of the results was also included on the survey. To gauge the reliability of this questionnaire, we carried out a test–retest study in which 113 introductory college chemistry students completed the survey on two separate occasions, two weeks apart. The results showed student responses to be exact in 60% of the cases and within one choice in 90%, producing reliability coefficients ranging from 0.46 to 0.69. The likelihood of a reversal in the direction of difference for an instrument with a

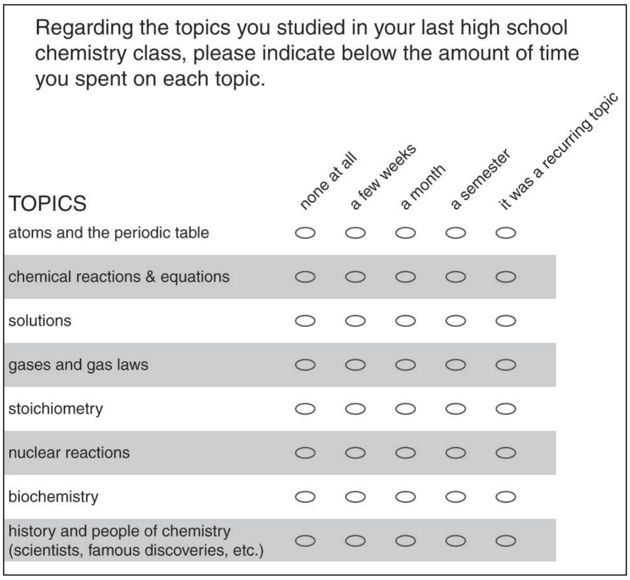

Figure 1. An example of the actual survey questions.

reliability coefficient of 0.40 in a group of 100 individuals is 0.7% *(11)*. This result indicates that survey reliability was acceptable.

Students' final introductory college chemistry grade (ICCGRADE) was used as the outcome measure. College course grades carry with them the weight of a permanent record that may have a bearing on students' future career prospects; something clearly understood by students. ICCGRADE represents a summative assessment of performance over an entire semester and is a common measure in previous studies *(1, 3–5, 10)*.

The control predictors used in this analysis fall into two groups: demographic identifiers and general educational background measures. The demographic identifiers include the following: gender, racial or ethnic background, parental education levels, average county household income, and high school type (i.e., public, private, magnet, charter, or parochial). Past studies have shown the importance of these predictors *(12, 13)*. General educational background measures account for differences in academic achievement and relevant coursework. These variables included (i) SAT–Math scores, (ii) last high school (HS) mathematics grade, (iii) last HS science grade, (iv) last HS English grade, (v) type of HS calculus course taken (if any), and (vi) AP chemistry enrollment (if any).

In choosing question predictors, the researchers consulted various sources including textbooks, high school teachers, and college professors. The eight Time on Topic predictors were selected as representative of varying degrees of content emphasis:

1. Atoms and the Periodic Table (Atoms)
2. Chemical Reactions and Equations (Reactions)
3. Solutions
4. Gases and Gas Laws (Gas Laws)
5. Stoichiometry
6. Nuclear Reactions
7. Biochemistry
8. History and People of Chemistry (History).

The topics were chosen to span the range from "fundamental" to "rarely included" in high school chemistry courses. Figure 1 shows an example of the actual survey questions. The analysis used multiple linear regression to produce an inferential statistical model assessing the significance of relationships between the Time on Topic predictors and the outcome, ICCGRADE, while controlling for background predictors.

Since the survey spanned different courses in different schools, differences in grading practices would be expected. Including only lecture–recitation–laboratory formatted courses limited some differences. However, other institutional and course-based differences need to be accounted for, as well. To address this issue, a set of "dummy" variables was included in the model to account for college effects. The statistical power of this analytical method offered a 90% chance of detecting a small effect *(14)*.

Incomplete questionnaires are not uncommon in large-scale surveys. Typically, a questionnaire is excluded from the analysis, a tactic that introduces problems of data loss and biasing *(15)*. In this study, missing data for the control predictors were imputed *(16–18)* to mitigate the problems imposed by systematic exclusion of incomplete surveys. Details on this approach are discussed in the Supplemental Material.[W]

Results and Discussion

Table 1 contains background data on the participating colleges and universities. Figures 2–4 show the distributions for the eight Time on Topic predictors. Figure 2 displays the graphs of the four high-occurrence predictors. A closer analysis of the graphs shows Atoms and Reactions have higher recurrence than Solutions and Gas Laws. This finding suggests that Solutions and Gases are typically included, but are fairly isolated within the curriculums, while Atoms and Reactions appear to be strong themes throughout high school chemistry. Figure 3 displays the distribution of the two moderate occurrence topics, Stoichiometry and History. The lower level of occurrence for Stoichiometry compared to Atoms and Reactions is somewhat surprising since the principles of stoichiometry are so closely associated with these two topics. A comparison of recurrence shows Stoichiometry and History have lower percentages than Atoms and Reactions, but higher percentages than Solutions and Gas Laws. Figure 4 displays the distributions for the low occurrence topics, Nuclear Reactions and Biochemistry.

The findings suggest four classifications: (i) high occurrence–high recurrence for Atoms and Reactions, (ii) high occurrence–low recurrence for Solutions and Gas Laws, (iii) moderate occurrence–moderate recurrence for Stoichiometry and History, and (iv) low occurrence–low recurrence for Nuclear Reactions and Biochemistry. The classifications suggest that the content topics included in this analysis do span the range from fundamental (Atoms and Reactions) to fairly rare (Nuclear Reactions and Biochemistry).

Table 2 shows the correlations among the eight content topics contained in the survey.[1] The highest correlation was found to be between Gas Laws and Solutions at $r = 0.610$, considered a moderate correlation in social science research. These results suggest that many students who reported covering Gas Laws also reported covering Solutions. The next

Table 1. Data on Colleges and Universities Participating in the Survey

School	Participants	Affiliation	Avg. ACT	Avg. SAT	School Size[a]	State
1	12	Public	23	1080	S	NY
2	13	Public	22	1050	M	WV
3	17	Public	22	1050	M	TN
4	21	Public	22	1020	M	GA
5	22	Private	21	1010	S	PA
6	23	Private	20	975	S	SC
7	30	Public	20	970	M	KY
8	34	Private	19	930	S	KY
9	36	Public	23	1080	M	NY
10	38	Private	22	1050	S	AZ
11	39	Public	17	830	S	CA
12	43	Private	25	1160	S	MI
13	43	Private	22	1050	S	IL
14	48	Private	23	1170	S	OR
15	57	Public	21	990	S	NH
16	59	Public	21	1000	M	TX
17	60	Public	23	1060	S	ME
18	68	Private	21	1010	S	MI
19	84	Public	24	1100	M	WA
20	88	Private	24	1120	S	AL
21	94	Public	22	1050	S	SD
22	118	Public	21	1010	L	CA
23	120	Private	26	1180	S	PA
24	134	Public	19	930	M	LA
25	155	Public	24	1110	L	AZ
26	177	Private	26	1200	S	IN
27	256	Public	23	1080	M	ID
28	271	Public	24	1120	L	LA
29	411	Public	27	1210	M	MD
30	434	Public	21	990	M	IN
31	516	Public	24	1120	L	KY
Totals	3521	20/11[b]	—	—	4/11/16[c]	22

[a]966 participants were from small schools (< 5000 FTE), 1495 were from medium-size schools (5000–15,000 FTE), and 1060 were from large schools (>15,000 FTE). [b]Public/private. [c]Large/medium/small.

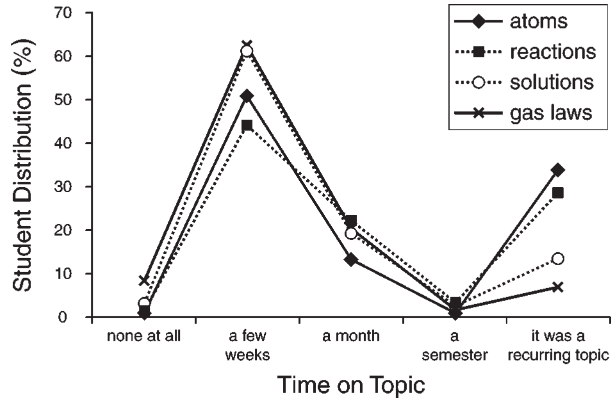

Figure 2. Percentage of students in high occurrence topics.

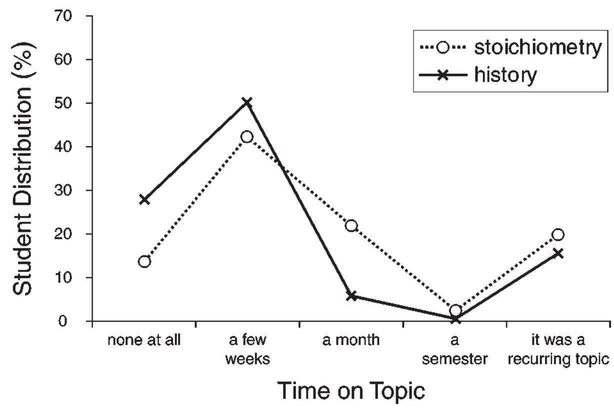

Figure 3. Percentage of students in moderate occurrence topics.

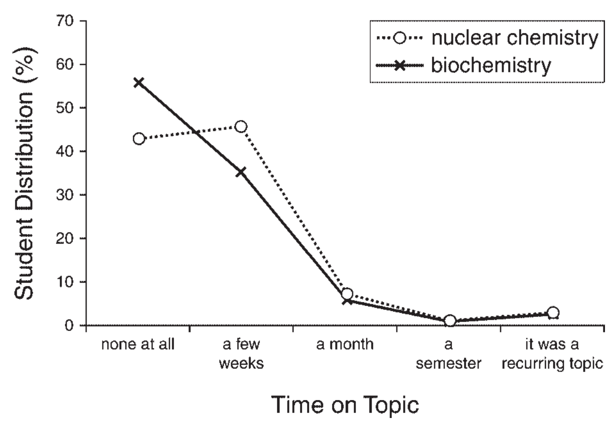

Figure 4. Percentage of students in low occurrence topics.

highest correlation was found to be between Nuclear Reactions and Biochemistry at 0.597. The moderate correlation between Nuclear Reactions and Biochemistry is consistent with a common struggle between breadth and depth. The third highest correlation occurs between Atoms and Reactions.

Next we consider differences across common levels of high school chemistry: regular, honors, and Advanced Placement. The average Time on Topic across each of the eight content areas was calculated for these three levels of high school chemistry. In order to make this calculation, the following numerical values representing the number of estimated instructional days were assigned to each of the five categories: Not at All = 0; A Few Weeks = 15 days; A Month = 20 days; A Semester = 40 days; Recurring Topic = 40 days.[5] The results are shown in Figure 5. This format allows for fairly straightforward comparisons. However, these percentages do not represent absolute percentages, since all possible chemistry topics were not included. A comparison of the relative percentages for regular and honors chemistry reveals them to be very similar. Small differences did appear for Atoms and Stoichiometry, where students in regular-level courses reported a greater focus on Atoms, while students in honors-level courses reported a greater emphasis on Stoichiometry. A stronger quantitative focus in honors is not surprising; however, the small difference is surprising. Regular- and honors-level chemistry appear to have very few differences in content-coverage patterns. When considering AP chemistry,

Table 2. Correlations between Content Topics

	Atoms	Reactions	Solutions	Gas Laws	Stoichiometry	Nuclear Reactions	Biochemistry	History
Atoms	1[a] (3284)[b]							
Reactions	0.579 (3262)	1 (3275)						
Solutions	0.419 (3237)	0.565 (3235)	1 (3252)					
Gas Laws	0.322 (3231)	0.410 (3231)	0.610 (3231)	1 (3247)				
Stoichiometry	0.337 (3237)	0.524 (3237)	0.435 (3219)	0.431 (3214)	1 (3253)			
Nuclear Reactions	0.201 (3209)	0.252 (3208)	0.371 (3191)	0.512 (3190)	0.302 (3202)	1 (3225)		
Biochemistry	0.162 (3223)	0.191 (3223)	0.310 (3204)	0.417 (3204)	0.227 (3216)	0.597 (3199)	1 (3239)	
History	0.195 (3234)	0.201 (3233)	0.174 (3211)	0.202 (3210)	0.177 (3217)	0.184 (3198)	0.203 (3216)	1 (3252)

[a]All correlations are significant at the 0.001 level (2-tailed test). [b]Sample sizes in parentheses.

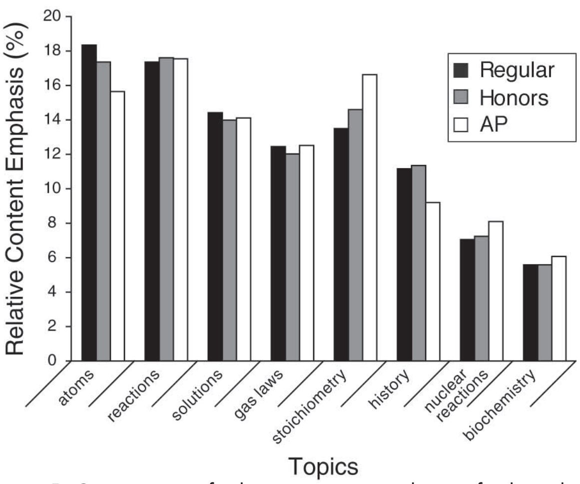

Figure 5. Comparison of relative content emphasis of selected topics across HS chemistry course levels.

the emphasis appears to be lower for Atoms compared to both regular and honors chemistry. Not surprising given that all the students who reported taking AP chemistry also reported taking a regular or honors chemistry course. AP chemistry also tended to have a weaker emphasis on History, but a stronger emphasis appeared for Stoichiometry, a quantitative topic, and Nuclear Reactions, an advanced topic. These results are consistent with common expectations that AP chemistry is more quantitative and advanced than the other levels.

Before continuing on to discuss the regression model, it is important to consider a methodological strategy used here when predictors did not have a normal distribution, as is the case with all eight Time on Topic predictors. These predictors cannot simply be entered in an analysis, since their distributions are non-normal and violate an initial condition for regression. A common tactic to overcome this problem is to convert these predictors into sets of binary variables. This approach is used for categorical predictors such as race or ethnicity and gender. Each response is used as a one component of a set of predictors, so for example None at All becomes a variable with two values, 0 or 1. Applying this approach produced eight sets of binary predictors or a "dummy variable" set. Each component of a dummy variable set may be compared with the other components, with one component held out of the model as the basis of comparison or a baseline. We chose the response, A Few Weeks, as the baseline for these eight sets (see the Supplemental Material[W] for a more detailed discussion).

Multiple linear regression has the capacity to simultaneously analyze the connections among many variables and compare the explanatory power of the predictors, allowing for a variety of alternative hypotheses to be compared and background differences to be controlled for. Demographic differences are important to control for. Certainly, students' personal resources, such as parents with college backgrounds would be expected to have an impact on their performance in college. Students' past academic records are important as well.

Table 3 shows the regression model for the outcome ICCGRADE. Significant background predictors included students' racial or ethnic background and parents' highest educational level. Students' year of college enrollment was only marginally significant when freshmen performance was compared to sophomores and not significant when compared to juniors and seniors. The significance of the racial and ethnic predictors reveals underachievement in minority groups traditionally underrepresented in chemistry, Hispanics and African Americans. Underachievement of African Americans is only marginally significant with underachievement of Hispanics showing stronger significance. Some studies have indicated complex social mechanisms that play important roles in student performance and persistence among students of color *(19)*. The outcome for Native Americans is significant; however, the sample only included 32 students. Further investigation of underrepresented minority groups is important though beyond the scope of this current manuscript.

The regression model also found the following general educational background predictors to be significant: high school calculus enrollment, AP chemistry enrollment, quantitative (Math) and verbal SAT scores, and high school grades in science, English, and mathematics. All of these predictors appear as highly significant predictors of ICCGRADE except for SAT–Verbal. The analysis showed that Last HS English Grade appeared to subsume some of the variance in ICCGRADE accounted for by SAT–Verbal scores. Though not surprising, these results do form the backbone of many traditional hypotheses accounting for college chemistry performance.

High school calculus enrollment, SAT–Math score, and Last HS Mathematics grade were all found to be highly significant in the same model indicating that each contributes independent predictive power for college chemistry success. The high β-values of these three variables surpass those of AP Chemistry and Time on Topic predictors and suggest that mathematics background is the most powerful predictor of student performance found in this analysis.

Turning our attention to the Time on Topic predictors, Table 3 shows that three of the eight content areas are significant predictors of ICCGRADE at the $\alpha = 0.05$ level. The connection between these predictors and ICCGRADE is fairly complex. In the case of Gas Laws, the parameter estimates show no significant difference between students who reported having content related to this topic for the duration of A Few Weeks, A Month, or Not at All experience in high school chemistry. In contrast, the model predicts that students who report having a strong emphasis on Gas Laws have predicted college grades that are 1.5 points lower on the average. On the scale used for this analysis, 1.5 points translates into about one sixth of a letter grade, a small effect.

Table 3. Regression Model[a] including Categorical Predictors for HS Chemistry Content Topics

Predictors		B[b]	SE[b]	β[b]
Constant		40.57[c]	1.98	–
College & University Dummy Variables		Included		
Demographic and General Education Predictors				
Race or Ethnicity	Not Reported	0.05	1.60	0.00
	Native American	-4.18[e]	1.77	-0.03
	Asian	0.07	0.64	0.00
	Black	-1.48[f]	0.76	-0.03
	Multi-racial	1.03	1.07	0.01
	Hispanic	-3.49[c]	0.81	-0.07
Highest Parent Education Level		0.47[d]	0.16	0.05
Year in College	Sophomore	-0.82[f]	0.45	-0.03
	Junior	-0.21	0.61	-0.01
	Senior	0.03	0.92	0.00
HS Calculus Enrollment	Regular	1.73[c]	0.50	0.06
	AP–A/B option	3.00[c]	0.46	0.11
	AP–B/C option	4.31[c]	0.76	0.09
AP Chemistry Enrollment		2.90[c]	0.56	0.08
SAT	Math	0.02[c]	0.00	0.15
Last HS Grade in…	Science	1.68[c]	0.27	0.11
	English	1.10[c]	0.31	0.06
	Mathematics	2.83[c]	0.26	0.19
Content Coverage Predictors				
Gas Laws	Not at All	0.74	0.65	0.02
	A Month	0.16	0.48	0.01
	Recurring Topic	-1.53[e]	0.76	-0.04
Stoichiometry	Not at All	-2.49[c]	0.56	-0.08
	A Month	0.09	0.48	0.00
	Recurring Topic	2.63[c]	0.50	0.10
Nuclear Reactions	Not at All	0.62[f]	0.37	0.03
	A Month	-0.68	0.71	-0.02
	Recurring Topic	-3.98[c]	1.03	-0.07

[a]Dependent variable: introductory college chemistry course grade (A+ = 98, A = 95, A- = 91, B+ = 88, etc.); R^2 = 0.355; Adj. R^2 = 0.341; Sample size = 3093. [b]B, parameter estimate; SE, standard error of the parameter estimate; β, standardized parameter estimate. [c]$p < 0.001$. [d]$p < 0.01$. [e]$p < 0.05$. [f]$p < 0.10$.

Stoichiometry background was found to be a much stronger predictor. Students reporting None at All were predicted to have a grade 2.5 points lower than the baseline of A Few Weeks, which translates to one quarter of a letter grade. Students who reported a heavy emphasis (i.e., recurring topic) were predicted to earn grades 2.6 points higher than the baseline, about one-quarter of a letter grade. Comparing heavy emphasis students to students reporting no Stoichiometry, heavy emphasis students were predicted to outperform their peers by half of a letter grade, on the average. No significant difference appeared between students reporting A Few Weeks versus A Month.

For the topic of Nuclear Reactions, the regression analysis shows that students reporting less emphasis on this topic typically have higher levels of performance. In fact, the regression results suggest that students reporting no Nuclear Reactions backgrounds in high school more typically earned higher college chemistry grades, while those reporting a heavy emphasis have college grades on the average, nearly half of a letter grade below their peers. Rather than finding the study of advanced topics is associated with later success, we find no particular benefit to making it through to the final chapters of the textbook. The number of heavy emphasis students totaled 132 (4% of the sample); though small, this total does provide enough representation to reveal significance.

The other five chemistry content topics were not found to be associated with introductory college chemistry grades. These topics were: Atoms, Reactions, Solutions, History, and Biochemistry. For Atoms and Reactions, only a few students selected the None at All response category. Here the comparison among the categorical predictors amounted to a comparison among students reporting A Few Weeks, A Month, and Recurring Topic. Atoms and Reactions are fundamental to chemistry understanding, and this result might be indicative of the pervasiveness of these topics. No difference is found between students who reported explicitly returning to these topics through out the semester versus others who reported A Few Weeks or A Month of coverage.

For Solutions and History, each reported substantial numbers of responses in all four categories, allowing each category to be strongly represented in the analysis. Particularly surprising is the absence of History as a significant predictor. It is to note that college chemistry grades may not be sensitive to the influence of history, often cited as a topic providing context, perspective, and generating student interest. Studies on student continuation in chemistry coursework might be more revealing. Finally, for Biochemistry, 109 individuals selected the heavy emphasis choices (3.5% of the sample); enough for the analysis, but unlike Nuclear Reactions, no significant results were found.

Table 4. Categorical Predictors' Ranges and Continuous Predictors' Ranges, Averages, and Standard Deviations

Predictor		Min	Max	Ave (s.d.)
Race or Ethnicity	Not Reported	0	1	Categorical
	Native American	0	1	Categorical
	Asian	0	1	Categorical
	Black	0	1	Categorical
	Multi-racial	0	1	Categorical
	Hispanic	0	1	Categorical
Highest Parent Education Level		0	4	2.73 (1.10)
Year in College	Sophomore	0	1	Categorical
	Junior	0	1	Categorical
	Senior	0	1	Categorical
HS Calculus Enrollment	Regular	0	1	Categorical
	AP–A/B option	0	1	Categorical
	AP–B/C option	0	1	Categorical
AP Chemistry Enrollment		0	1	Categorical
SAT	Math	220	790	590 (100)
Last HS Grade in...	Science	1	5	4.4 (0.8)
	English	1	5	4.6 (0.6)
	Mathematics	2	5	4.3 (0.8)
Gas Laws	Not at All	0	1	Categorical
	A Month	0	1	Categorical
	Recurring	0	1	Categorical
Stoichiometry	Not at All	0	1	Categorical
	A Month	0	1	Categorical
	Recurring	0	1	Categorical
Nuclear Reactions	Not at All	0	1	Categorical
	A Month	0	1	Categorical
	Recurring	0	1	Categorical

A regression model is actually a multidimensional linear equation where the parameter estimates (shown in Table 3) are the coefficients of the variables shown in Table 4. Written out, the linear equation is fairly extensive.

ICCGRADE = 40.57 + 0.05(Race Not Reported) − 4.18(Race Native American) + 0.07(Race Asian) + ... + 0.47(Highest Parent Education Level) − 0.82(Year in College: Sophomore) + ... + 1.73(HS Calculus Enrollment Regular) + 3.00(HS Calculus Enrollment AP A/B) + ... + 2.90(AP Chemistry Enrollment) + 0.02(SAT–Math Score) + 1.68(Last HS Science Grade) + ... + 0.74(Gas Laws: None) + 0.16(Gas Laws: A Month) − 1.53(Gas Laws: Recurring Topic) + ...

However, calculations are fairly straightforward. For example, suppose we wish to compare two prototypical students: Student A who had stoichiometry as a recurring topic in high school and Student B who had no stoichiometry. Suppose these students have the same background characteristics in every other way. Table 5 displays a comparison of the two linear equations used to produce the predicted ICCGRADE. The results predict a final grade of 84.26 for Student A and 79.16 for Student B: B, and C+, respectively. Other predictions may be made by using the regression model in a similar fashion.

Conclusions

Based on this analysis, we found Stoichiometry to be the one chemistry topic among a group of eight to be an important predictor of college chemistry performance.[6] The predicted grade of students who reported a heavy emphasis on stoichiometry was 2.6 points higher than their peers who reported studying stoichiometry for A Few Weeks or A Month. However, compared to students who reported no stoichiometry, the heavy emphasis students were predicted to earn grades 5.1 points higher. Class time and emphasis committed to stoichiometry varies widely in high school. Both the textbooks and classroom practice reflect this variation. We found evidence of a continuum in the survey responses with students reporting stoichiometry content experiences that ranged from Not at All to a Recurring theme throughout their high school chemistry course. Comparing high school to college chemistry content emphases, stoichiometry is seldom

Table 5. Comparison of Predicted ICCGRADE for Two Prototypical Students

Predictor		*B*	Student A[a]	Student B
Constant		40.57	1	1
Race or Ethnicity	Not Reported	0.05	0	0
	Native American	-4.18	0	0
	Asian	0.07	0	0
	Black	-1.48	0	0
	Multi-racial	1.03	0	0
	Hispanic	-3.49	0	0
Highest Parent Education Level		0.47	3	3
Year in College	Sophomore	-0.82	0	0
	Junior	-0.21	0	0
	Senior	0.03	0	0
HS Calculus Enrollment	Regular	1.73	1	1
	AP–A/B option	3.00	0	0
	AP–B/C option	4.31	0	0
AP Chemistry Enrollment		2.90	1	1
SAT	Math	0.02	590	590
Last HS Grade in...	Science	1.68	4	4
	English	1.10	4	4
	Mathematics	2.83	4	4
Gas Laws	Not at All	0.74	0	0
	A Month	0.16	1	1
	Recurring Topic	-1.53	0	0
Stoichiometry	Not at All	-2.49	0	1
	A Month	0.09	0	0
	Recurring Topic	2.63	1	0
Nuclear Reactions	Not at All	0.62	1	1
	A Month	-0.68	0	0
	Recurring Topic	-3.98	0	0
Predicted ICCGRADE[b]			84.26	79.14

[a]Student A with stoichiometry as a recurring topic in HS chemistry and Student B with no stoichiometry. Both prototypical students are white, have a parent that graduated from college and are freshmen. [b]Predicted ICCGRADE: A+ = 98, A = 95, A- = 91, B+ = 88, B = 85, B- = 81, C+ = 78, C = 75, C- = 71, etc.

studied before the second quarter of the academic year. However, in college chemistry, students need to master stoichiometric calculations very early, often by the first or second week of the first course. In college chemistry textbooks, the topic is generally introduced by the third chapter. Some high school chemistry curricula and textbooks have chosen to take a qualitative or conceptually-based approach, de-emphasizing stoichiometry. The study of stoichiometry necessarily includes the application of mathematics, which also appears as a highly significant predictor of college performance.

The influence of mathematics is evident in light of the significance of three predictors: HS Calculus Enrollment (regular, Advanced Placement A/B, or B/C), SAT–Math score, and Last HS Mathematics Grade as predictors. A surprising finding is the importance of calculus enrollment. Why does calculus appear to be so valuable in introductory college chemistry, especially since courses typically require few, if any, calculus applications? Our view is that facility with solving simple equations and comprehending graphs, an essential skill in college chemistry, over time and with practice. While advanced mathematics is not used in introductory chemistry, studying topics such as calculus in high school raises the likelihood that students show fluency in algebra with no scaffolding or teacher-support. In college, students who have not acquired these skills with full mastery are at a substantial disadvantage, since chemistry professors do not "hand-hold" students with weak mathematical skills. Instead, professors assume that students enrolled in their classes possess the proficiency to follow lectures and comprehend text passages without assistance regarding mathematical symbols and equations. Lack of fluency in mathematics, the "language of science", handicaps introductory chemistry students, just as being a tourist in a foreign land limits one's experience if you do not know the local language.

Taking this discussion a step further, we wondered whether college chemistry students would specifically mention the term "stoichiometry" on their own if asked about their chemistry learning experiences. Therefore, to provide some limited qualitative corroboration of our statistical findings, we searched supplementary post-survey emails from respondents who completed our original survey and granted us permission to contact them with follow up questions. Among others, students were asked the following question: What aspects of your high school chemistry course helped you most in college? The following are excerpts from the responses of six students that specifically used the term stoichiometry:

> I think *stoichiometry* gave a lot of kids trouble so I think my fairly strong background with that gave me a heads up.
>
> ...*stoichiometry*—I learned that really well in high school and I remembered it all throughout chemistry.
>
> ...knowledge about *stoichiometry* from high school chemistry helped me most.
>
> I'd have to say *stoichiometry* because quite a few people had problems with that."
>
> ...*stoichiometry* and the ability to apply conversions helped the most.
>
> ...most helpful was the depth [with which] we covered *stoichiometry....*

These responses summarize the impact of stoichiometry in college chemistry. For the high school chemistry teachers who choose to spend more time on stoichiometry and less time on other more advanced topics, the results support their decision and suggest that this practice gives their students a significant advantage in introductory college chemistry.

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[w]Supplemental Material

A method to deal with missing data and an analytical approach for using non-normally distributed variables are discussed in this issue of *JCE Online*.

Notes

1. These schools are a subset of 67 selected through stratified random sampling based on school size from a comprehensive list of nearly 1700 four-year colleges and universities in the United States. Since nearly half of all students attending four-year colleges and universities are enrolled in only 10% of the country's higher institutions, stratified random sampling ensured that the sample would be nationally representative. The chemistry departments of all selected schools were contacted and asked to participate. Instructors at 31 schools agreed.

2. This format is by far the most ubiquitous and thus the format most likely to be experienced by introductory chemistry students.

3. Though retrospective self-report surveys are very common and include the National Assessment of Education Progress and the National Educational Longitudinal Survey of 1988, limitations are important to consider and include accuracy and reliability. Conclusions from early research questioning accuracy and reliability *(20)* have shifted in light of more recent studies that suggest memory and recall can be quite reliable even over extended periods of time when contextual cues are provided *(20–22)*. Other researchers *(23–26)* have identified several additional factors to improve recall that include: proper wording of questions, grouping questions into conceptually related sequences, providing contextual cues within the questionnaire, surveying students in situations and surroundings associated with the topic, and making the survey relevant to the students. The survey methodology accounted for all of these factors.

4. Apart from revealing associations among the content topics, a correlation analysis provides some details regarding associa-

tions among the predictors and provides some hints to the problem of multicollinearity in the regression analyses that may play havoc with the significance statistics and produce misleading results. Checking correlations provides one means of detecting this problem; another means of detection includes a systematic and careful approach to the inclusion of variables in each regression model.

5. The values were chosen as fractions of a 180 day school year, consisting of 36 weeks or 9 months. Dividing 180 days by 9 months produces a value of 20 days for each month. The category of A Few Weeks was given the value of 15 days, five school days shorter than a month. The categories for A Month and Recurring Topic were chosen to represent two differing approaches to instruction, highly intensive, long term content focus and repeated exposure to content over an extended period of time. Both of these categories were intended to represent long time commitments to particular content areas. Therefore, rather, the distinguishing characteristic between these two categories was not actual time, but the formatting of the time. Thus for the purposes of this calculation, the categories, A Month and Recurring Topic, were given a value twice as large as the value for a month, i.e., 40 days.

6. Some readers might wonder whether the students surveyed in our study would know the term stoichiometry. The students participating in this study were typically surveyed 4–10 weeks into an introductory college chemistry course at a four-year college or university and all students included in this analysis also reported having had at least one high school chemistry course. This level of formal chemistry education suggests that students would be very likely to be familiar with this term.

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