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High School Chemistry Instructional Practices and Their Association with College Chemistry Grades

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Nearly half of the students graduating from high school in 2005 (47.4%) entered four-year colleges or universities *(1)*. Data from the National Educational Longitudinal Study of 1988 shows more than 90% of science teachers place a moderate-to-major emphasis on college preparation *(2)*. Studies dating as far back as the 1920s have looked for connections between high school chemistry preparation and college performance *(3)*. More recent studies have considered these factors in predicting college chemistry performance: SAT–Quantitative section test scores *(4–6);* mathematical ability *(5–7);* mathematics coursework *(6);* chemistry background *(8–10);* and chemistry placement test scores *(10–12)*. Though these achievement measures are important predictors of success in college, they are beyond the control of high school chemistry teachers. However, high school teachers do have a greater degree of control over the choices they make about what happens in the classroom, about the instructional practices they use. Therefore it seems important to ask whether the choices about instructional practice have a significant association with college performance. Do teachers' decisions about how many demonstrations to use, how often to lecture, or whether to use peer teaching, have a connection to their students' performance in college chemistry? This study will focus on the analysis of classroom practices, some common, some less common, and their connection with performance in first-course introductory college chemistry.

Methodology

This investigation studies a sub-sample of data from a nationally representative survey of introductory college science students, entitled *Factors Influencing College Science Success* (Project FICSS, NSF-REC 0115649). Beginning in Fall 2002, Project FICSS has surveyed over 100 introductory college science courses in biology, chemistry, and physics at 56 four-year colleges and universities from an initial list of 67 selected through stratified random sampling based on school size from a comprehensive list of over 1700 schools. All surveyed courses fulfilled science course requirements for science and engineering majors.

The subsample included 3521 students from 38 different first courses in introductory college chemistry sequences taught at 31 four-year colleges and universities (20 public; 11 private) in 2002 and 2003 fall semesters. Some schools that were asked to participate chose not to. As a result, in order to guard against any systematic bias between participating and nonparticipating schools, we compared them across measures such as school size, admissions selectivity, or geographic location and found no results indicating bias based on self-selection. Located in 22 different states, schools ranged from small liberal arts colleges to large state universities. For continuity in comparison across courses, we chose to include only courses with the lecture–recitation–laboratory format, by far the most common and therefore the most likely to be experienced by high school students continuing on to college chemistry. Students were surveyed during class sessions and final grades were provided by course instructors. All individually identifiable information was stripped from the surveys before data were scanned.

Though retrospective self-report surveys are very common (e.g., National Assessment of Education Progress),[1] accuracy and reliability are important considerations. Early research raised concerns with regard to these considerations *(13)*. However, more recent studies found that recall can be quite accurate when contextual cues are provided, even over a period of years *(14–16)*. Factors to improve recall 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 surveying students on issues relevant to them *(17–21)*. The survey design accounted for each of these factors and included background information explaining the purpose and eventual use of the results. Questionnaire development took into account feedback from college professors and high school teachers, field testing with introductory college chemistry students, and interviews with student focus groups. Questionnaire reliability was analyzed through a separate test–retest study involving 113 introductory college chemistry students who completed the survey on two separate occasions, two weeks apart. The study produced reliability coefficients ranging from 0.46 to 0.69; acceptable in light of research citing that a reliability coefficient of 0.40 for a group of 100 indicates that an outcome has a less than 1% chance of reversal in future studies *(22)*.

Final college chemistry grade (introductory college chemistry grade, or ICCGRADE) was used as the outcome measure, representing performance in introductory college chemistry. College course grades are permanent records that students clearly understand may be highly relevant to their future career plans. In addition, ICCGRADE is typically a composite of many measures taken over the course of several months and represents a summative assessment of performance on many occasions.

Q01: How many demonstrations did your teacher conduct each week?
o None o 1 o 2 o 3 o 4 o More than 4

Q02: How long did you discuss the procedure or make predictions before each of your teacher's demonstrations?
o Not at all o 5 minutes o 10 minutes o Half of the class o A whole class or more

Q03: How long did you discuss the outcome after each of your teacher's demonstrations?
o Not at all o 5 minutes o 10 minutes o Half of the class o A whole class or more

Please indicate how often the following activities or events occurred:

		Very rarely	Once/ month	Once/ week	2-3 times/ week	Everyday
Q04:	The teacher lectured to the class	o	o	o	o	o
Q05:	Work in small groups	o	o	o	o	o
Q06:	Spent time doing individual work in class	o	o	o	o	o
Q07:	Whole class discussions were held in your class	o	o	o	o	o
Q08:	Examples from the every day world were used	o	o	o	o	o
Q09:	Tests or quizzes were given	o	o	o	o	o
Q10:	Teaching your classmates	o	o	o	o	o
Q11:	Class time was spent preparing for standardized science exams	o	o	o	o	o
Q12:	Participated in chemistry-related community projects	o	o	o	o	o

Figure 1. Example of instructional practice survey questions, labeled Q01–Q12.

The control predictors used in this analysis fall into two groups: demographic identifiers and general educational background measures. The demographic identifiers included: gender, racial–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 predictor variables *(23, 24):* (a) SAT–Mathematics scores, (b) Last high school mathematics grade, (c) Last high school science grade, (d) Last high school English grade, (e) Type of high school calculus course taken (if any); and (f) Advanced Placement (AP) chemistry course enrollment (if any).

This study included 12 instructional practice predictors on teaching methods, such as demonstrations and frequency of lectures, whole class discussions, small group work, tests, and peer teaching. Figure 1 is a mock-up of the survey questions. These 12 predictors are labeled Q01–Q12 for reference, while more descriptive terms will be used in the text for clarity.

The analysis applied multiple linear regression analysis, which has the capacity to analyze the significance of instructional practice variables as predictors of the outcome measure, ICCGRADE, while controlling for background differences. Given the breadth of the survey, some course-level or school-level differences would be expected and are commonly referred to as college effects. Including only lecture–recitation–laboratory formatted courses offered a degree of comparability. To address this issue more comprehensively, a set of variables representing each college was included in the model to account for grading variations across different college courses. This technique has been found to be most useful when studying differences among students rather than among colleges, which is the purpose of our study. The statistical power of this analytical method offered a 90% chance of detecting a small effect *(25).* Another challenge for large-scale surveys is incomplete questionnaires. In this study, missing data for the control predictors were imputed *(26–28)* using the expectation–maximization algorithm to mitigate data loss and biasing *(29).* Additional details of the analytical approach are discussed in a previous work *(30).*

Results and Discussion

This section consists of three parts: a descriptive analysis of instructional practice predictors for an overview of trends in instructional practices; a multiple linear regression analysis to identify significant associations between these predictors and ICCGRADE; and a comparison of prototypical students to provide a more concrete interpretation of the findings.

Descriptive Analysis

Table 1 displays percentages of students' responses to the 12 instructional practice predictors. The results for Demonstrations (Q01) indicate that most students recall their high school teachers presenting 1–2 demonstrations each week. However, students reported very little time spent on discussion, with 88.1% reporting 10 minutes or less on pre-demonstration discussion (Q02) and 78.5% reporting 10 minutes or less on post-demonstration discussion (Q03). Most common was lecture (Q04) with 90.6% of students selecting the choice "2–3 Times per week" or "Everyday". Also common were small group work (Q05) with 75.6% and individual work (Q06) with 75.4% of the respondents reporting frequencies of at least once a week. Whole class discussion (Q07) appears to be less common, with 66.2% reporting frequencies of at least once a week. Tests and quizzes (Q08) appear to have occurred most often on a weekly basis, with monthly as the next most common choice. The use of everyday examples (Q09) was widely distributed, with more than 10% of the students reporting in each of the five choices. Most commonly selected was "Once per week" at 30.3%. Peer teaching (Q10), standardized exam preparation (Q11), and participation in community projects (Q12) were all used much less frequently, with a majority selecting "Very rarely" in each case. For peer teaching, 34.8% of the students reported once monthly or once weekly use; however, higher frequencies of "2–3 times per week" at 8.6% and "Everyday" at 5.5% were not rare, representing 280 and 179 students, respectively. For standardized exam preparation, the two higher frequency choices accounted for a total of 251 students. For community projects, 83.1% responded with "Very rarely"; only a total of 248 students responding in the three higher frequency choices. A common technique to bolster student representation in under-populated response choices is to group together adjacent responses. The two highest frequency responses for exam preparation and the three highest frequency responses for community project were grouped together for the regression analysis.

Regression Analysis

Summarized in Table 2, the regression analysis identified five of the twelve predictors as significant at the $\alpha = 0.05$ level, with one predictor significant at the weaker $\alpha = 0.10$ level. The standardized parameter estimates, β, show that the instructional practice predictors individually have less impact than the demographic and general education background controls. However, the collective impact cannot be disregarded, especially since these instructional practices are typically experienced in combination. Demonstrations (Q01), individual work (Q06), exam preparation (Q11), and community projects (Q12) all indicated negative associations with the outcome, ICCGRADE. This result suggests that students reporting higher frequencies of these instructional practices in their high school chemistry classes typically earned lower college chemistry grades. However, peer teaching (Q10) and everyday examples (Q09) both produced positive associations, with students who reported higher frequencies more typically earning higher college grades.

Among the nonsignificant predictors were pre- and post-demo discussions (Q02 and Q03, respectively). These results, coupled with the negative parameter estimate for number of demonstrations per week (Q01), may imply that current high school chemistry practice with regard to demonstrations is not effective in enhancing college chemistry performance. However, readers should be cautioned from drawing the conclusion that demonstrations are not helpful. This current study has several important limitations. First, it only considered quantity of demonstrations and length of pre- and post-demo discussions. Other instructional practices directly linked with demonstrations might yield different results. Second, this study does not address the issue of student interest and

Table 1. Frequency Distribution for Instructional Practice Predictors

Predictors	Incidence of Student Exposure to 12 Varied Instructional Practices						Number of Students
			Number per Week, %				
Instructional Practices	None	1	2	3	4	More than 4	Total *(N)*
Q01: Demos	9.6	39.5	26.4	15.2	4.3	5	3268
			Portion of Class Time, %				
		Not at All	5 minutes	10 minutes	Half of the Class	Whole Class +	
Q02: Pre-Demo. Discussion		14.5	33.5	40.1	11.2	0.7	3309
Q03: Post-Demo. Discussion		9.6	24.8	44.1	20.5	0.9	3292
			Frequency of Practice, %				
		Very Rarely	Once/Month	Once/Week	2–3 times /Week	Everyday	
Q04: Lecture		2.4	2.1	4.9	23.3	67.3	3283
Q05: Small Group Work		8.9	15.5	38	27.3	10.3	3267
Q06: Individual Work		12.9	11.7	28.1	29.4	17.9	3268
Q07: Whole Class Discussion		21.6	12.1	23.2	23	20	3267
Q08: Tests and Quizzes		2.2	28.8	57.8	8.4	2.8	3252
Q09: Used Everyday Examples		13.6	15.7	30.3	25.2	15.2	3251
Q10: Peer Teaching		51.2	20.9	13.9	8.6	5.5	3261
Q11: Standardized Exam Prep.		54.4	26	11.8	4.9	2.8	3268
Q12: Community Projects		83.1	9.3	4.7	2	0.9	3258

continuation in chemistry. Demonstrations are typically used to spark students' interest and imagination. The impact of demonstrations might be associated with student continuation in chemistry from high school to college. This subject deserves further investigation, but is beyond the scope of this current study. The findings do suggest that the quantity of demonstrations does not appear to improve performance in college chemistry. Other nonsignificant predictors include frequency of lecture (Q04), small-group work (Q05), whole-class discussion (Q07), and tests and quizzes (Q08).

Comparing Two Prototypical Students

Calculations of the predicted ICCGRADE differences associated with differing values of the instructional practice variables produce very small differences in students' predicted grades. For example, a student who reported very rarely doing individual work is predicted to have an ICCGRADE that is 1.5 points higher than another student who reported doing individual work every day. This point difference amounts to less than one-fifth of a letter grade. However, none of these instructional practices are carried out in isolation. In fact, teaching practice often involves a combination of the original 12 (and even more) instructional practices into an overall instructional approach. As a result, the predictors should be considered as a group, rather than individually.

An effective means of analyzing these coupled predicted effects is the comparison of prototypical students. Since the parameter estimates of a regression model are the coefficients

Table 2. Linear Regression Model Including Instructional Practice Predictors[a, b]

Predictors		B, Parameter Estimate	Standard Error	β, Standardized Parameter Estimate
Constant		42.21[c]	2.05	
College Effects Dummy Variables		Included	Included	Included
Demographic and General Education				
Race/Ethnicity	Not Reported	0.40	1.59	0.00
	Native American	−1.48	1.72	−0.01
	Asian	0.25	0.64	0.01
	African American	−1.73[d]	0.78	−0.04
	Multi-Racial	0.76	1.09	0.01
	Hispanic	−3.15[c]	0.81	−0.06
Highest Parent Education Level		0.60[c]	0.16	0.06
Year in College	Sophomore	−0.88[f]	0.45	−0.03
	Junior	−0.08	0.62	0.00
	Senior	−0.27	0.92	0.00
HS Calculus Enrollment	Regular	2.01[c]	0.50	0.06
	AP A/B	3.17[c]	0.47	0.12
	AP B/C	4.30[c]	0.77	0.09
AP Chemistry Enrollment		3.45[c]	0.57	0.10
SAT Scores	Quantitative	0.02[c]	0.00	0.16
	Verbal	0.00	0.00	0.02
Last HS Grade in …	Science	1.73[c]	0.27	0.11
	English	1.03[c]	0.31	0.06
	Mathematics	2.81[c]	0.26	0.19
Instructional Practice				
Q01: Demonstrations/Week		−0.36[e]	0.14	−0.04
Q06: Individual Work		−0.38[d]	0.14	−0.04
Q09: Everyday Examples		0.27[f]	0.15	0.03
Q10: Peer Teaching		0.34[e]	0.15	0.04
Q11: Standardized Exam Prep.		−0.63[d]	0.20	−0.05
Q12: Community Projects		−0.76[e]	0.33	−0.04

[a]Dependent variable: Introductory college chemistry course grade ($A^+ = 98$, $A = 95$, $A^- = 91$, $B^+ = 88$, $B = 85$, …).
[b]$R^2 = 0.340$; Adjusted $R^2 = 0.327$. [c]$p < 0.001$. [d]$p < 0.01$. [e]$p < 0.05$. [f]$p < 0.10$.

$$
\begin{aligned}
\text{ICCGRADE} = 42.21 & \\
& - 0.40 \text{ (Race: Not Reported)} \\
& - 1.48 \text{ (Race: Native American)} \\
& - 0.25 \text{ (Race: Asian)} \\
& + 0.60 \text{ (High Parental Education Level)} \\
& - 0.88 \text{ (Year in College: Sophomore)} \\
& + 2.01 \text{ (High School Calculus: Regular)} \\
& + 3.45 \text{ (AP Chemistry)} \\
& + 0.02 \text{ (SAT Quantitative)} \\
& + 1.73 \text{ (Last High School Math)} \\
& - 0.36 \text{ (Demos per Week: Q01)} \\
& - 0.38 \text{ (Individualized Work: Q06)} \\
& + 0.27 \text{ (Examples: Q09)} \\
& + 0.34 \text{ (Peer Teaching: Q10)} \\
& - 0.63 \text{ (Standardized Exam Prep: Q11)} \\
& - 0.76 \text{ (Community Projects: Q12)}
\end{aligned}
$$

Figure 2. Linear equation displaying connection between parameter estimates, predictors, and outcome (ICCGRADE).

of a linear equation, the solution of this equation is a predicted value of the outcome variable, ICCGRADE. A sketch of the equation is provided in Figure 2. Table 3 shows the range of values for the predictors. Substituting values in the equation, the predicted ICCGRADE for a prototypical student may be calculated.

The following example compares the predicted college chemistry performance of two prototypical students with identical demographic and general educational backgrounds, but with different experiences in terms of instructional practice. Suppose both prototypical students had average SAT scores, good grades, some calculus background, but no AP chemistry background. Suppose Student A reported that his teacher frequently performed more than four demonstrations each week; frequently required students to work individually on class assignments; and frequently engaged students in standardized exam preparation, while at the same time the teacher rarely engaged students in peer teaching; rarely used everyday examples; and did not involve the student in community projects. Conversely, suppose Student B reported that her

Table 3. Categorical Predictors' Ranges and Continuous Predictors' Ranges, Averages, and Standard Deviations

Predictors		Minimum	Maximum	Average (SD)
Race/Ethnicity	Not Reported	0	1	Categorical
	Native American	0	1	Categorical
	Asian	0	1	Categorical
	African American	0	1	Categorical
	Multi-Racial	0	1	Categorical
	Hispanic	0	1	Categorical
Highest Parent Education Level		0	4	2.7 (1.1)
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	0	1	Categorical
	AP—B/C	0	1	Categorical
AP Chemistry Enrollment		0	1	Categorical
SAT Scores	Quantitative Section	220	790	590 (100)
	Verbal Section	200	800	570 (100)
Last High School Grade in...	Science	1	5	4.4 (0.8)
	English	1	5	4.6 (0.6)
	Mathematics	2	5	4.3 (0.8)
Q01: Demonstrations/Week		0	5	1.8 (1.2)
Q06: Individual Work		1	5	3.3 (1.3)
Q09: Everyday Examples		1	5	3.1 (1.2)
Q10: Peer Teaching		1	5	2.0 (1.2)
Q11: Standardized Exam Prep.[a]		1	4	1.7 (1.0)
Q12: Community Projects[b]		1	3	1.2 (0.6)

[a]Responses "2–3 times per week" and "Everyday" grouped together into "Multiple times per week" and assigned a value of 4 for regression analysis.
[b]Responses "Once per week", "2–3 times per week", and "Everyday" grouped together into "Weekly" and assigned a value of 3 for regression analysis.

teacher frequently engaged students in peer teaching and frequently used everyday examples, while at the same time the teacher rarely performed demonstrations; rarely required students to work individually; rarely engaged students in standardized exam preparation, and also did not involve students in community projects. Table 4 shows the values substituted into the regression model and the predicted ICCGRADE values calculated. Student B's predicted ICCGRADE is 84.1, while Student A's predicted ICCGRADE is 77.2. The difference is 6.9 points, with a predicted grade of B for Student B versus C+ for Student A.

Conclusions

Trends in the predictors (i.e., the signs of the parameter estimates, B) show that peer teaching (Q10) was associated positively with higher grades, while individual work (Q06) was negatively associated. Intuitively, this outcome suggests that students who reported more frequently peer teaching and less time working alone tended to perform better in college. Though statistically weaker, the use of everyday examples (Q09) is positively associated with college performance as well. Demonstrations (Q01) appeared to be negatively asso-

Table 4. Comparison of Predicted ICCGRADE for Prototypical Students A and B Reporting Differing High School Chemistry Instructional Practice Experiences

Predictors		Parameter Estimates	Prototypical Student A	Prototypical Student B
Constant		42.21	1	1
College Effects—Baseline		0		
Demographic and General Education				
Race/Ethnicity	Not Reported	0.40	0	0
	Native American	-1.48	0	0
	Asian	0.25	0	0
	African American	-1.73	0	0
	Multi-Racial	0.76	0	0
	Hispanic	-3.15	0	0
Highest Parent Education Level		0.60	3	3
Year in College	Sophomore	-0.88	0	0
	Junior	-0.08	0	0
	Senior	-0.27	0	0
HS Calculus Enrollment	Regular Calculus	2.01	1	1
	AP A/B	3.17	0	0
	AP B/C	4.30	0	0
AP Chemistry Enrollment		3.45	0	0
SAT Scores	Quantitative Section	0.02	590	590
	Verbal Section	0.00	570	570
Last HS Grade in …	Science	1.73	5	5
	English	1.03	5	5
	Mathematics	2.81	4	4
Instructional Practice				
Q01: Demonstrations		-0.36	5	1
Q06: Individual Work		-0.38	5	1
Q11: Standardized Exam Prep.		-0.63	4	1
Q12: Community Projects		-0.76	1	1
Q10: Peer Teaching		0.34	1	5
Q09: Everyday Examples		0.27	1	4
Predicted Final College Grade (ICCGRADE)			77.2	84.1
Predicted Letter Grade Equivalent[a]			C^{+}	B

[a]Scale for ICCGRADE: A = 95, B = 85, C = 75, D = 65, … .

ciated with performance. The reports of limited class time devoted to both pre-demo and post-demo discussion suggests that demonstrations were not typically used as a means of encouraging discussion in a teacher-guided framework. Community projects (Q12) were found to be negatively associated with student performance. However, an overwhelming majority of students selected "very rarely" in response to class-related community projects in high school chemistry, suggesting this predictor may suffer from a lack of variance. Judgment should be reserved until further research has been undertaken. For the variable standardized exam preparation (Q11), also found to be negatively correlated to college chemistry performance, the responses were more widely distributed across the range of possible choices. Since this variable clearly did not suffer from a lack of variance, this finding garners more confidence.

High school chemistry teachers' decisions about their daily practice appear to be associated with their students' later performance in introductory college chemistry. Though the predicted effects are small when taken individually, considered collectively as an instructional approach, the predicted differences are fairly large. The results suggest that instructional practices that encourage structured peer teaching are positively associated with performance in college chemistry.

Note

1. U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, National Assessment of Educational Progress Home page. *http://nces.ed.gov/nationsreportcard/* (accessed Mar 2007).

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