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## High school Class-size and College Performance in Science

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*This paper focuses on the influence of high school science class size on students' achievement in introductory college science courses and on the variation of teacher practice across class size. Surveys collected information about high school science class experiences from 2754 biology, 3521 chemistry, and 1903 physics students across 36 public and 19 private institutions from 31 different states. The first analysis includes a cross-tabulation of 6 different class sizes and the frequencies of teacher practices reported by students. The second analysis includes a multiple linear regression of class size and student achievement. Results show no differences for pedagogy and student achievement until class sizes fall to 10 or fewer students. These findings suggest that incremental reductions in class size are likely not to have a significant impact on later student achievement.*

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### Introduction

Optimizing opportunity for student success (Starratt, 2005) while considering the burden imposed on the community by the cost of such an environment puts educators, teachers and administrators, under immense pressure and often at odds. Demands of the standards movement brought on by federal policies such as *No Child Left Behind* (ERIC 2003) has further stressed this balance. Among the choices that derive from these efforts are those related to staffing and class sizes. Debates on appropriate class size have polarized school communities. Educators, administrators, parents, and government officials, all take stands on one side of the divide or the other, leaving decision-making officials under great pressure to weigh the cost of reducing class size against the potential benefits. In the January 23, 2006 edition of the *Burlington Free Press*, Molly Walsh outlined the dilemma for the state of Vermont, which had the lowest student-teacher ratio in the nation that year.<sup>1</sup> Not surprisingly the issue came down

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<sup>1</sup> An important point on terminology, "student-teacher ratios" include all adults in a school, not just classroom teachers. Administrators, librarians, guidance counselors and special education teachers are often included in this calculation. On the other hand, "class size" generally refers to the number of students being taught by a teacher in one class. (Ehrenberg et al., 2001; Finn et al., 2001; Miller-Whitehead, 2003).

to a balance between a highly effective education and the cost of these small classes. Maintaining the #1 class size ranking has pushed the cost per student up to \$11,608 with the national average around \$8,700 (NCES, 2004). The state Tax Commissioner summed up the conflict by relating the state's high property tax issues to the low student-teacher ratio, "...if they make that choice, they can't at the same time complain about their property taxes".

In this manuscript we focus on the teaching methods used across class sizes and the influence class size has on science learning. Science scores on the NAEP test at the 12th grade level slightly decreased in recent years with 57% of our seniors scoring at the "basic" level in 1996 and only 54% achieving the same level in 2005. Scores at the proficient level also decreased over the same time period from 21% to 18% (NCES 2006). In section 2 of a 2002 amendment on the Undergraduate Science, Mathematics, Engineering, and Technology Education Improvement Act, congress stated "A workforce that is highly trained in science...is crucial to generating the innovation that drives economic growth..." (Committee on Science, 2002). Given the national importance ascribed to science, it seems that an analysis of the impact of class size on student achievement may help guide policymakers in deciding how to initiate long-range efforts to reverse negative trends in students' achievement and persistence.

#### *Project STAR and the Class Size Debate*

There is no question that class size has great influence on the cost of education. The question remains, what influence does class size have on student achievement? Supporters of smaller class sizes report that smaller classes lead to better teaching and more effective learning. Molnar (2000) claims benefits such as greater focus on instruction for teachers and improvement in student behavior, more individual attention and opportunity for participation for students. The study perhaps at the epicenter of the debate is the Tennessee Student Teacher Achievement Ratio (STAR) project. Achilles (1999), the STAR principal investigator, argues that "conscientious educators" should consider smaller classes as an investment in the futures of both the students and society. In fact, much

of the existing research regarding class size is based on data collected from STAR, which involved K – 3 students in Tennessee from 1984 to 1999. The program began with more than 6,000 kindergarten students randomly assigned to three types of classes: small classes (13-17 students), regular classes (22-25 students), and regular classes with a teacher's aide. The students were followed for four years as a part of the initial project and many studies evaluating the progress of these students have ensued. The data from STAR has been analyzed in a variety of ways and the findings have been widely publicized (Finn, Gerber, Achilles, & Boyd-Zaharias, 2001; Finn, Gerber, and Boyd-Zaharias, 2005; Hanushek, 1999; Nye and Hedges, 2001a, 2001b).

Published studies include Nye and Hedges (2001a) who reported finding that there were cumulative positive effects in reading and mathematics at the elementary level for smaller classes. In a subsequent publication, Nye and Hedges (2001b) claim these effects can still be observed six years hence, even when students returned to larger classes. Mishel and Rothstein (2002) offer the following summary, "...students in small classes performed significantly better than those in regular classes or regular classes with aides in kindergarten and...the achievement advantage of small classes remained constant through the third grade" (p. 55).

However, not all agree there is enough evidence of student improvement to counter the cost. Greene (2005) raised criticisms with the lack of a pre-test and questioned the reliability of the STAR data. Blatchford (2003) reasoned that the study only compared two class sizes and suggested that this represented only a narrow range. He also points out that the research design was susceptible to the Hawthorne Effect since participants were aware of their role in the experimental design. In addition, Hanushek (1999) reported that only 48% of the original sample actually completed the experiment, raising questions about sample bias. Apart from these criticisms, STAR project has produced an abundance of analysis and remains the largest study of its kind on class size.

*Beyond Elementary School*

The enormity of the literature on class size at the elementary level accentuates the relative void of research on older students. Using the STAR data, Finn et al. (2005) performed an analysis of graduation rates comparing students among the three groupings. The study found that students who attended small classes for 3 or more years in elementary school were more likely to graduate from high school, with a stronger effect among students who were eligible for free lunch. However, this study looked at outcomes at the high school level with class size effects from elementary experiences, not secondary experiences. Few studies have collected analyzed data on the effects of class size effects beyond elementary school. An exception is Rice's (1999) analysis of data from analyzed NELS:88 data. Her study focused on the effect of class size on the use of instructional strategies in high school science and mathematics classes. She reported that class size did appear to have an effect in mathematics classes, though these findings were not replicated in her analysis of science classes.

Bryk, Lee, & Holland (1993) studied Catholic parochial schools, which commonly have larger classes compared to public schools, and found that student achievement is typically higher, despite larger class sizes and lower levels of funding. However, extracting the effect of class size from the context of Catholic parochial schools is futile given that the elements of religion and private schooling pervade the analysis.

In a summary analysis of class size coalescing data from four sources including survey studies, international comparisons, and econometric data, Hanushek (1998) concluded that class size reductions are ineffective in promoting student achievement. The results from this summary analysis offered by Hanushek, seem to provide a conclusive response to the impact of class size on student achievement. However, though initially impressive in scope, Hanushek's analysis has weaknesses. For example, his use of "basic aggregated data" makes expansive assumptions by applying cross-sectional data in analyses better suited to longitudinal data sets. Associated analyses of interna-

tional data and econometric data take similar approaches. In short, Hanushek's analysis links averaged student performance to average pupil-teacher ratio without direct reporting of students' experiences. Finally, he includes an analysis of the previously discussed STAR data carried out on early elementary aged children, rather than an analysis of students at the secondary level, grade level of the students in the earlier analyses. We conclude from this review of existing studies on class size that an analysis of a direct association between class size experience in high school and subsequent achievement has not been carried out. We hope our analysis will offer some assistance in bridging this gap in the literature.

Our analyses addressed two questions. The first question has to do with the student experience in the high school science classroom. Do teacher methods change in response to class size? There are some analyses strongly supporting the idea that what teachers do in the classroom matters to student achievement. In 1996, Sanders and Rivers analyzed data from the Tennessee Value-Added Assessment System (TVAAS) and found that teacher effects on students are long-lasting. A later analysis on students in Dallas Public Schools upheld these findings (Jordan, Mendro, & Weerasinghe, 1997). In these studies, teachers were assigned to quintiles based on student gains in their classrooms. Teachers who produced the greatest student learning gains were assigned to quartile 5, while those who produced the lowest student gains were assigned to quartile 1. Using this approach, the Dallas researchers were able to put students into cohorts based on the succession of teachers the students experienced for three years. They found that students who had teachers that were in the higher quartiles made greater gains in math and reading than those students who experienced teachers in lower quartiles. In addition, findings from the California Class Size Reduction initiative suggest that at least some instructional practices differ with smaller class sizes (Strecher and Bohrnstedt, 2002).

The existing literature suggests that what teacher's do in the classroom and how they do it, matters to student learning. In our study, we

analyzed the frequencies of six different teacher methodologies across varying class size in order to explore the various experiences of the students.

Our second research question is, is the size of high school science classes associated with higher student achievement in college science? Our study takes a novel approach to the measurement of achievement. Rather than the usual outcome of achievement tests, which represent one-shot measures of student performance, we use final college grades from introductory college science courses as a measurement of student achievement. In doing so our study represents an outcome that is more widely understood to have an impact on students' futures and career prospects. We perform a regression analysis that looks for a correlation between student high school science class size and subsequent performance in the first course of introductory college science while controlling for several demographic and educational background variables. Given that most high school science teachers report preparation for further study as a major emphasis in their teaching (Hoffer, Moore, Quinn, & Suter, 1996), we feel this study would provide some additional insight into the role of class size in student achievement.

### Methods

This investigation is based on data collected through a national 4-year study entitled *Factors Influencing College Science Success* (Project FICSS). Funded through the Interagency Educational Research Initiative and administered through the National Science Foundation (NSF-REC 0115649), Project FICSS surveyed introductory college science students regarding their high school science experiences and also collected these students' grades in these courses (Author, 2001). Given the study's agreement to maintain confidentiality, all collected data were stripped of individually identifiable information and are reported only in an aggregated analysis.

In this investigation, we use a subset of the Project FICSS surveys. This analysis studied data collected from students enrolled in first semester of college biology, chemistry, and physics courses at 55 different 4-year colleges

and universities in the fall semesters of 2002 and 2003. The sample included students from 36 public and 19 private institutions from 31 different states, and encompassed 128 different classes selected through a stratified random sampling of 1700 4-year colleges and universities from a comprehensive list.<sup>2</sup> Faculty from science departments within the colleges and universities were asked to participate and instructors from 29 biology departments, 31 chemistry departments, and 37 physics departments agreed. We compared participating and non-participating schools across measures such as school size, admissions selectivity, and geographic location and producing no indication of self-selection bias. Of 8178 surveys used for this analysis, 311 were not included because of non- or multiple responses to questions. An analysis of the excluded surveys did not show them to be clustered within the sample. In addition, we also performed a data clustering analysis through the use of students' reported home ZIP codes, the largest clustered numbered 29 and 33, representing 0.0035% and 0.0040% of the overall sample. Given the size of the overall sample, the impact of these student clusters would be negligible.

To maintain consistency in our data, we surveyed only large lecture-based classes with smaller recitation/tutorial sections and separate laboratory sessions.<sup>3</sup> This format is by far the most common and thus, most likely to be experienced by college students. The FICSS surveys were administered during class meetings. Later, college instructors entered the students' final course grades on the surveys before returning the surveys. As part of the protocol, student identification was physically removed from the survey forms and destroyed after grades had

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2 Approximately 60 percent of students in higher education settings attend 4-year colleges and universities. The balance attended 2-year institutions (i.e. junior colleges, community colleges). (United States Department of Labor, July 2005)

3 At this point, we wish to comment on the issue of high school and college class size. It seems natural to suggest that larger high school classes may better prepare students for larger college classes. However, a very large high school science class may have introductory college science courses are in general disproportionately larger than even the largest high school classes, making the argument of larger high school classes as a means of college preparation seem much less credible.

been matched. The sample totals are: 2754 biology surveys, 3521 chemistry surveys, and 1903 physics surveys.<sup>4</sup> Based on these sample sizes, statistical power analysis indicate that our study has a greater than 90% chance of detecting a small effect with a 0.20 correlation (Light, Singer, & Willett, 1990).

Several actions were taken in effort to enhance the accuracy and reliability of the data. The survey was created to incorporate several characteristics that have been identified as important to enhancing accuracy.<sup>5</sup> Some skeptics may cite the rather well-worn and over-generalized belief that “self-reports are not accurate,” a conclusion that can be traced back to a study by Bradburn, Rips, & Shevell (1987) published in the journal *Science*. However, subsequent research including studies by Bradburn have concluded that dismissing all forms of self-report as inaccurate was a mistake. Kuncel, Credé and Thomas (2005) summarized much of the existing literature associated with educational research. In this review, they concluded that surveys of specific populations on topics relevant to these groups provide reasonably accurate results. This review specifically cites college students. Asking introductory college science students about their high school science experiences in the respective science disciplines offers a reasonable degree of accuracy enhancement.

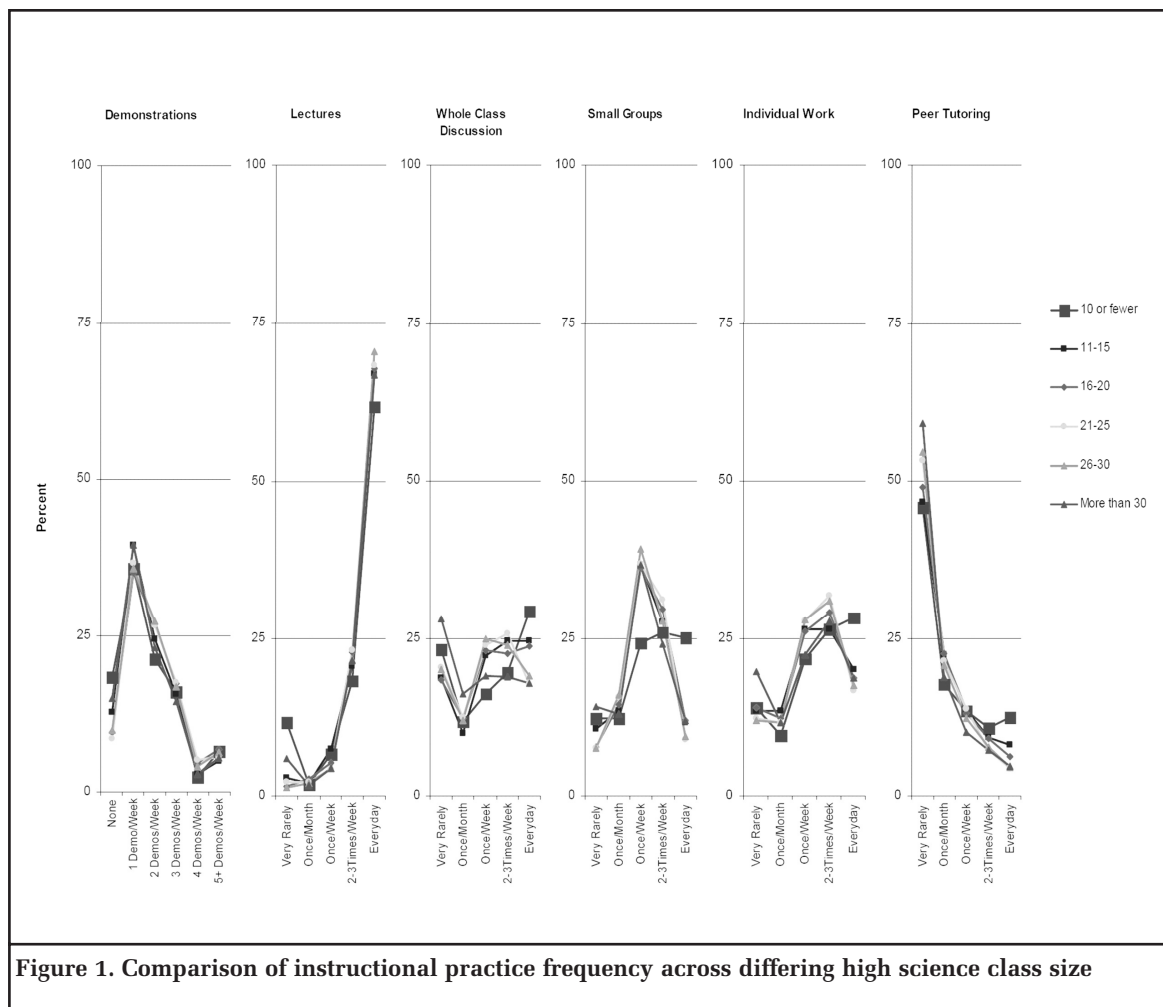
To evaluate the reliability of the survey, a separate test-retest study involving 113 introductory college chemistry students was conducted. These students completed the survey on two occasions, two weeks apart. The study produced reliability coefficients ranging from 0.46 to 0.69, which is considered acceptable for aggregated analyses of groups greater than 100 individuals (Thorndike, 1997). Our sample includes several thousand students.

## Results

We begin our discussion by considering teaching methods across differing class-sizes. For this analysis, we cross-tabulated class-size with the student reported frequencies of the following instructional practices in science: 1) demonstrations; 2) lectures, 3) whole class discussions, 4) small group activities, 5) individual work, and 6) peer tutoring. See Figure 1. For demonstrations, we found the student-reported frequency distributions to be very similar across the number of weekly demonstrations they recalled experiencing. For the other five instructional practices, we noted differences in frequency distributions most evident when comparing the smallest class size category, *10 or fewer*, to the larger class size categories. For lectures, individual work, and peer tutoring, we found the differences to be most evident at the extremes, with larger class size categories generally reporting lower frequencies of peer tutoring and individual work and greater frequencies of lectures. For whole class discussions and small groups, the differences in frequency distributions were much more evident. It appears that whole class discussions were primarily a weekly activity for class sizes larger than 10, while for classes of 10 or fewer the greatest frequencies were at the extremes, either daily or very rarely. On the other hand, work in small groups appeared to be weekly, though not daily activities for larger classes, while for classes of 10 or fewer students, the distribution was fairly even across weekly to daily frequencies. While differences in frequencies appear to exist between class sizes of 10 or fewer and larger classes, the frequency distributions for classes larger than 10 students are very consistent across all 6 pedagogies, with the exception of class sizes larger than 30. Though very similar across five instructional practices, the frequency distributions were markedly different with respect to whole class discussions, with classes larger than 30 students using this technique less frequently. Though some variation in instructional technique frequency across science class sizes, the frequency distributions are remarkably similar for high school class sizes between 11 and 30 students. This result is consistent with Rice (1999).

<sup>4</sup> A total of 2647 physics survey were collected. However, 744 college physics students reported not having taken high school physics (28.1 percent). These students were not included in the analysis.

<sup>5</sup> These factors included: a) proper wording of questions, b) grouping questions in conceptually related sequences, c) providing contextual cues, d) surveying students in situations and surroundings associated with the topic, and e) making the survey relevant to the students (Niemi & Smith, 2003).



Next, we turn to an analysis of the association of high school science class size and college science performance, as measured by the final course grade. The survey asked students to report on the class size of the high school science course corresponding to their college science course by selecting one of 6 class size categories: 10 or fewer students; 11-15; 16-20; 21 – 25; 26-30; and More than 30. Treating these as categorical variables, we compared each category to the median class size category, 21 – 25. The regression model also included variables controlling for differences with respect to stu-

dents’ educational and demographic backgrounds. See Table 1. The analysis indicated that only students reporting class sizes of 10 or fewer performed significantly different from their peers who reported high school class sizes of 21 – 25 students. The difference in performance was 1.42 points, or 1/6th of a letter grade, at the  $\alpha < 0.01$  level of significance. The result indicated that the effect the model attributed to smaller class sizes is rather small. However, interpretations of these results should be made with caution.

Main Effects Variables		B <sup>c</sup>	s. e. <sup>c</sup>	β <sup>c</sup>
Constant		38.81 ***	1.39	
College & University Indicators		Included		
<u>Demographic Background</u>				
Highest Parent Education Level		0.51***	0.12	0.05
Race/Ethnicity	Not Reported	1.05	1.09	0.01
	Native American	-1.22	1.02	-0.01
	Asian	-0.72	0.44	-0.02
	Black	-3.66***	0.51	-0.08
	Multi-racial	0.34	0.72	0.00
	Hispanic	-1.85***	0.53	-0.03
<u>Educational Background</u>				
SAT	Quantitative	.02***	.00	0.14
	Verbal	.01***	.00	0.06
AP Science Enrollment		1.87***	.29	0.07
HS Calculus Enrollment	Regular	1.90***	0.33	0.06
	AP – A/B	3.05***	0.31	0.11
	AP – B/C	4.22***	0.50	0.09
Last HS Grade in...	Science	1.86***	.18	0.12
	English	1.22***	.206	0.07
	Mathematics	2.51***	.17	0.17
<u>Class Sizes</u>	10 or fewer	1.42**	0.53	0.03
	11-15	0.35	0.42	0.01
	16-20	-0.35	0.31	-0.01
	26-30	0.47	0.28	0.02
	More than 30	0.31	0.51	0.01

<sup>a</sup> Dependent Variable: Introductory College course grade (A+ = 98, A = 95, A- = 91, B+ = 88, etc.)

<sup>b</sup> R<sup>2</sup> = 0.332; Adj. R<sup>2</sup> = 0.318; Sample size = 7618

<sup>c</sup> B, parameter estimate; s. e., standard error of the parameter estimate; and β, standardized parameter estimate

\*\*\* p < 0.001, \*\* p < 0.01, \* p < 0.05, ~ p < 0.10

**Table 1. Multiple linear regression models of class size and instructional practices with background predictors <sup>a b</sup>**

The findings here are limited by the populations we chose to sample. Introductory college science students taken as a whole may be considered high academic achievers in comparison to high school students taken as a whole. These results indicate that among high academic achievers, the influence of class size is significant, though small. This finding is not inconsistent with findings that suggested that smaller class sizes may differentially benefit lower achievers.

Finally, this study does not control for teacher quality. The use of multiple linear regression analysis would require a quantifiable measure of teacher quality. We have not found any such validated measure. As a result, we proceeded under the assumption that teacher quality was not biased with regard to class size. We have not found any existing research to indicate the existence of a teacher quality bias associated with class size.

### **Conclusions**

This study included 6 different class sizes which allowed for a more detailed analysis of class size differences, than previous studies based on comparisons of “large” and “small” class sizes. Our analysis of student-reported pedagogical experiences reveals fairly consistent frequency patterns with respect to demonstrations, lectures, and peer tutoring across different class sizes. However, some differences in frequency patterns were found among other instructional practices such as whole class discussions, small groups, and individual work. These results are similar to findings reported by Rice (1999).

The regression analysis result indicated that class size, after controlling for educational and demographic background differences, was a significant predictor of college science performance, but only produced a small effect for the smallest class size category, 10 or fewer. At first, this finding appears to support the contention of critics that class size reduction produces little to no effect. However, we caution the reader from drawing this conclusion without a consideration of the context of the study. The study sample was drawn from the population of sci-

ence students in introductory biology, chemistry, and physics courses at 4-year colleges and universities. Clearly, these students are representative of high academic achievers are by highly selective in comparison to the general high school population. In fact, previous studies discussed earlier have suggested that class size reductions are more effective with low academic achievers (Boozer and Rouse, 2001; Nye et al, 2001; Mosteller, 1995). Therefore, rather than offering evidence that class size reductions are ineffective, this result suggests that even among high achieving students in science at 4-year colleges, class size does have a significant association with performance, albeit a small one and only for classes of 10 or fewer students. The larger question regarding the association of class size and student performance for a more general population of high school students remains largely unaddressed.

It seems intuitive that decreasing the number of students a teacher is responsible for will change the experience of the students and ultimately increase the students' achievement. Our expectation at the onset of this study was to find a linear relationship between class size and achievement, and to offer evidence clearing up the class size debate relieving the pressure burdening our administrators. Though our results are not as expected, we did find that students experiences in regard to pedagogy across class sizes are very similar, and still some improvements were realized by students who were least expected to benefit. There are many questions that are not answered by our study. The students who are expected to benefit the most from smaller classes are not represented here and attention clearly needs to be focused on this population to further address the class size debate. It also is not clear how high school science methodology is associated with class size, and how this in turn associates with college science performance, if at all. Do instructional practices and class size interact differentially to produce effective learning? Are the findings for elementary school children replicated among secondary school children? Many questions still remain regarding the impact of class size on teaching and learning.

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