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Gender and Science Learning Early in High School: Subject Matter and Laboratory Experiences

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This study used a large and nationally representative, longitudinal database, NELS:88, to identify important factors related to gender differences in 10th-grade science performance. It built on an earlier study focusing on 8th-grade science performance, wherein gender differences were found to be related to (a) subject matter (life versus physical science), (b) student ability level, and (c) frequency of hands-on lab opportunities. The moderate unadjusted advantage for 8th-grade boys on the physical science test widened by the 10th grade. The gender differences were smaller on the life science test and favored males among students of average and above-average ability and females among the less able students. Hands-on lab activities—relatively infrequent in high school science classes—continued to be related to all students' performance, but especially to girls'. These findings suggest the importance of the active involvement of students in the science classroom as a means to promote gender equity. Implications for the underrepresentation of women in physical science careers are discussed.

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The role of gender in determining students' interest and performance in school science continues to attract attention from both scholars and the general public. Why do boys consistently outperform girls on standardized tests of science achievement? Why does this "gender gap" in science achievement increase as students move through the educational pipeline? The explanations that have been offered for this pervasive and troubling educational phenomenon focus both on individuals and on their educational experiences.

The study discussed in this article is a follow-up of an earlier study (Lee & Burkam, 1996) that investigated these questions for students at the end of their eighth-grade year. Here, we followed the same students whose science achievement we first studied in the eighth grade, exploring their experiences in science during their first 2 years of high school. Using data from the first two waves of the National Educational Longitudinal Study of 1988 (NELS:88, 1994), we investigated gender differences in science achievement for a nationally representative sample of 12,120 U. S. high school sophomores (in 1990).

As with our earlier work on this topic, this study breaks the more generic "science achievement" on the NELS standardized tests into two components: life science and physical science. The study focuses on students' early high school science experiences—reported by the students themselves and by their science teachers—in both the classroom and the laboratory. We are especially interested in how the relationship of these experiences to science achievement in the two domains differs for adolescent males and females, and in identifying the experiences that are especially salient for young women. Before presenting results of this study, however, we review the relevant literature on which the work is based. We also describe the earlier study on which this study builds.

Background

Importance of Content Domain

Achievement. The underrepresentation of women in science fields, as well as female underachievement in science, receives much attention in education research and in the popular press. A gender gap in science achievement that favors boys is reported as early as age 9, and the gap widens as students progress through junior high and high school (Jones, Mullis, Raizen, Weiss, & Weston, 1992). Because so few studies of performance in science in elementary and secondary school have separated science into its subject-matter specializations, the research on gender differences in science has probably consistently underestimated the gender gap in science achievement.

A few exceptions to this include a study reporting results from the periodic National Assessments of Educational Progress (NAEP) in science by Jones et al. (1992) and our previous study (Lee & Burkam, 1996). The two

studies examining gender differences by content domain documented a differing gender gap by subject, with the major deficit for females located in the physical, rather than biological science domain. Using the NELS:88 data, we reported that by the end of eighth grade, girls' achievement in physical science was significantly lower than that of counterpart boys, although in life science girls had a very slight advantage (Lee & Burkam, 1996). These early female disadvantages preface the subsequent pronounced and persistent underrepresentation of women in technical professions, particularly in the physical sciences and engineering.

Another recent study used the NELS:88 data to explore factor-analytic structures in the 8th- and 10th-grade science tests (Hamilton, Nussbaum, Kupermintz, Kerkhoven, & Snow, 1995). The authors identified four underlying factors in the 8th-grade test, but only three in the 10th: Quantitative Science (QS), Spatial-Mechanical (SM), and Basic Knowledge and Reasoning (BKR). There were large gender differences favoring males on the SM factor, small differences favoring males on the QS factor, and negligible differences on the BKR factor. It should be noted that most of the SM and QS items, however, dealt with the physical sciences, while most of the BKR items related to the life sciences.

Choice. Girls who wish to pursue science are sometimes encouraged to concentrate in biology. There is evidence that high school students believe that physical science is more masculine than biological science. Biology, often considered to be a "softer" science than chemistry or physics, is seen as a helping science, people-oriented, and nurturing—characteristics typically associated with females (Jones & Wheatley, 1990). In one girl's words,

I have always associated chemistry and physics with boys, and I have always associated biology with girls. So when I thought of chemistry, I thought, well, boys mostly, so I just scored it out. I don't see why a girl shouldn't be able to do chemistry and physics. I'd like to have carried on with them, but, as I said before, boys' subjects, so I just dropped them. I chose biology because it seemed to cover more areas of life, whereas chemistry and physics seemed to be only pouring liquids, powders, and gases into test tubes which didn't really appeal to me. Biology I thought . . . could be of help to me in the future . . . But I could not understand much reason to know whether one liquid was heavier than the other . . . (Kelly, 1987)

Because girls are typically more concerned about the human dimensions of science than more abstract scientific principles, experiments, or instruments (Jones & Kirk, 1990), their discussion of career choices within the field is focused on the life sciences. Girls more than boys say that their interest in science stems from wanting to help people, animals, plants, or the earth (Jones & Kirk, 1990; Kahle, Parker, Rennie, & Riley, 1993). Laboratory-based sciences and physical sciences are often rejected by girls because they cannot make affective links between those subjects and what they care

about. In one study, girls used the expression “scientist scientist” to distinguish individuals working in the physical sciences from those in the biological sciences (Baker & Leary, 1995).

Although the gender gap in many scientific fields is closing, women continue to be seriously underrepresented in undergraduate and graduate programs in many areas and in most scientific and technical professions. At the college level, females who major in science as undergraduates are much more likely to select biology and pre-med programs than physical science (chemistry, physics, engineering). Men pursuing postsecondary science degrees more often choose the physical sciences (Frazier-Kouassi et al., 1992). Clearly, “science” achievement and “science” interest are often too broadly defined to be very informative in the detailed investigation of gender differences.

Beyond the issue of subject matter, we have organized our review of relevant research on gender differences in science around three general questions: (a) Who is especially vulnerable to these differences? (b) When do these differences emerge? (c) Why do these differences emerge?

Who? High-Ability Students and Science Achievement

In our earlier work, we reported a troubling finding: The most able eighth-grade girls showed the largest disadvantage in physical science achievement relative to their male counterparts (Lee & Burkam, 1996). This result is consistent with the 1992 assessment of science proficiency by NAEP, which also reported wider gender gaps favoring males at high levels of proficiency (Jones et al., 1992). A multivariate study from the Study of Mathematically Precocious Youth also reported several gender differences among very high achievers (Swiatek & Benbow, 1991). Although many observed differences did not reach the level of statistical significance, the study’s results formed a consistent pattern: Talented male students pursued mathematics and/or science coursework and advanced degrees more vigorously than equally talented females. These findings have been consistent across several decades of research on mathematically precocious youth (Benbow & Stanley, 1980).

Using six national longitudinal data sets from the last 30 years (including NELS:88, High School and Beyond, and the National Longitudinal Study of Youth), Hedges and Nowell (1995) discussed two stable patterns related to gender, ability level, and science achievement. First, variability in mathematics and science achievement scores has been consistently larger for males than females. These small differences, ranging from 3% to 15%, did not change over time. Furthermore,

small mean differences combined with modest differences in variance can have a surprisingly large effect on the number of individuals who excel. There is evidence . . . that people who have careers in science and engineering are overwhelmingly more likely to have scores in the

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90th percentile on mathematics tests in high school. Sex differences in variance and mean lead to substantially fewer females than males who score in the upper tails of the mathematics and science ability distributions and hence are poised to succeed in the sciences. (Hedges & Nowell, 1995)

Consequently, among high-ability students—the pool of future scientists—females are doubly disadvantaged: Not only are they underrepresented as a group, but they are even further outperformed by other high-ability males, resulting in a larger gender gap than at average ability levels.

When? The Role of High School Science

A growing body of literature draws attention to the saliency of students' experiences in high school science. Gender differences in science achievement, though initially small in middle grades, become more substantial as students progress through high school (Jones et al., 1992). Moreover, the fact that secondary school science courses are optional is cited as a critical filter blocking entry into science disciplines for the many students who opt out of academic coursework in general, and science in particular (Brickhouse, Carter, & Scantlebury, 1990; Lovely, 1987).

Students' courses of study are differentiated little during middle grades; all students follow more or less the same curriculum. Coursework in science is thus a weak predictor of science achievement for middle-school students. The number and types of courses taken become stronger predictors of achievement in high school, as U. S. adolescents have considerable latitude to choose among science courses to fulfill their 2- or 3-course science requirement for graduation. The courses differ considerably in topic, intensity, and difficulty, and some students may choose to take no science course in a given year. Although the gender gap in science coursetaking has narrowed over time, high school girls continue to elect somewhat fewer advanced mathematics and science courses than boys (Oakes, 1990).

Why? Determinants of Gender Differences

The factors explaining gender differences in science performance and persistence that focus on individuals include participation (Kahle & Lakes, 1983; Kahle, Matyas, & Cho, 1985), cultural and social expectations (Jones & Kirk, 1990; Jones & Wheatley, 1990; Kelly, 1981; Morse & Handley, 1985), and such individual characteristics as attitudes, motivation, spatial ability, and interest (Cannon & Simpson, 1985; Jones & Wheatley, 1990; Simpson & Oliver, 1985, 1990). Those focusing on schools center on differential teacher expectations (Crossman, 1987; Jones & Wheatley, 1990; Spear, 1987) and classroom influences and environment (Eccles, 1989; Jones & Wheatley, 1990; Morse & Handley, 1985). Relevant to this study is the school factor, opportunity to learn.

Opportunity to learn. Opportunities to learn occur both in school and at home. Gender differences in science opportunities are most likely an

outgrowth of perceived gender-appropriate stereotypes. Parents and teachers who see science as a male domain, or science as more important for boys, may offer their daughters or female students fewer opportunities for science activities than boys. As a result of differential encouragement (and other reasons too), girls have fewer opportunities to learn science than boys.

In school, boys participate in more extracurricular science activities and experience more science-oriented activities than girls: for example, manipulating scientific equipment or participating in science field trips and camps. Typically, even young boys enter their elementary classrooms with more science-related experiences (Kahle & Lakes, 1983). These gender differentials in activities increase as students progress through school (Kahle et al., 1985). There are gender differences in science competitions, with males competing more than females. Among the girls who participate, more compete in the biological sciences than physical sciences (Jones, 1991). Such differences do not stem from lack of interest among girls, for they often express a desire to be more involved in science activities than they are. What they lack are the experiences themselves and the confidence and interest generated by such experiences (Kahle et al., 1993). A paucity of science experience lowers understanding, which may contribute to negative attitudes about the subject.

A common research theme is that teacher-directed instruction and whole-group instruction are detrimental to girls' science learning (Baker, 1987; Casserly, 1980; Eccles, 1989; Morse & Handley, 1985; Peterson & Fennema, 1985; Tobin & Garnett, 1987). In teacher-directed science classrooms, boys typically dominate nearly every type of interaction—from disciplinary to direct questions. In such classrooms, teachers also ask boys academically-related questions more often than girls (Lee, Marks, & Byrd, 1994; Sadker & Sadker, 1994). The trend toward male dominance increases in eighth grade, particularly with student-to-teacher interactions (Morse & Handley, 1985).

Enhanced learning opportunities for high achievers are more often available to male students. Males are more likely to enroll in advanced mathematics and science courses. Unlike lower level courses, these advanced courses, mostly enrolling students in the academic track, are often taught by more qualified teachers and include higher quality instruction (Oakes, 1990). In addition, teachers assign high-ability boys to top mathematics groups more than high-ability girls (Hallinan & Sorensen, 1987). Teachers are known to interact more frequently with boys than girls in high school mathematics and science classrooms, particularly in groups of high-ability students (American Association of University Women [AAUW], 1992; Becker, 1981; Eccles, MacIver, & Lange, 1986; Jones & Wheatley, 1990; Oakes, 1990; Parsons, Kaczala, & Meece, 1982; Sadker & Sadker, 1986, 1994).

Review of Our Earlier Study on Which This Research Builds

The study described here is a follow-up to our previous study, the purpose of which was to identify the nature of the early gender gap in science

achievement (Lee & Burkam, 1996). Using data from a large and nationally representative sample of eighth graders in a random sample of U. S. middle-grade schools drawn from NELS:88, we investigated many aspects of school science at the eighth grade that are relevant to this study. We divided science achievement by subject-matter (physical vs. life science). Consistent with the multidimensional nature of science achievement as discussed by Oakes (1990), we included covariates of several types: (a) demographic characteristics of students other than gender (social class [SES], race/ethnicity, ability in science, interest in and orientation toward science); (b) the curricular emphasis and the structure of eighth-grade science classes (subject-matter focus and regular laboratory component); and (c) the characteristics of science teachers (gender, experience, and preparation to teach science).

Three hypotheses drove our previous study: (a) The gap is not constant across subject matter; (b) it varies by ability of the student; and (c) it is related to course content and emphasis. All three were confirmed. For eighth graders, the gender gap favoring boys was primarily in physical science. This gap was larger for higher ability students (those from which the supply of future women scientists would most likely be drawn). The laboratory component of eighth-grade science classes (which occurred for only about a quarter of the students) had no impact on physical science achievement for boys but improved girls' achievement in this subject area.

The study described here was designed to build on this work. Using the first and second waves of data from NELS:88, we followed the same students from the eighth grade into high school, where they were surveyed and tested at the end of 10th grade. Our initial purpose was to investigate whether the earlier findings from the middle grades persisted after students had experienced science in the first 2 years of high school. Specifically, as students mature (and have more choices and specialization in the science curriculum), do the gender differences reported earlier increase or change over time?

Research Questions

Do these science achievement patterns remain in place midway through high school? Do the gender differences increase over time, as suggested by other studies? Three specific research questions guided our current study of adolescents in their first 2 years of high school.

- *Research Question 1: Subject matter.* Are gender differences in 10th graders' science achievement differentiated by the subject matter of the test? Guided by our earlier work, we hypothesized that the overall gender gap on an assessment of physical science knowledge would continue to favor 10th-grade boys. We also expected that gender gaps in both science areas would increase over time. The slight gender gap favoring 8th-grade girls in knowledge in life science might remain constant at 10th grade (or switch to favor boys), but it would probably be small in comparison to the gender gap in physical science achievement.

- *Research Question 2: Ability.* Do gender differences in 10th-grade science achievement remain differentiated by the students' ability level? Will gender differences continue to be largest for the most able students? We hypothesized that gender differences in physical science achievement would continue to be largest for the most able students. Consistent with the general trend in science achievement that progressively favors boys, the hypothesized female advantage in the life science (stated above) might disappear not only among the most able students but also among all students.
- *Research Question 3: Active, hands-on science experiences.* Do students benefit from a learning environment that involves them in regular laboratory work and other active learning techniques? Are these approaches to learning science particularly effective for girls' understanding? Following our previous research, we hypothesized that such activities would be beneficial for all students, but especially for girls.

Method

Sample and Data

The sample was drawn from the first two waves of the National Education Longitudinal Study of 1988 (NELS:88). NELS began as a general-purpose study of the educational status and progress of about 25,000 eighth-grade students in 1,035 American middle-grade schools, sponsored by the National Center for Education Statistics (NCES) (Ingels et al., 1994). The NELS base-year data had a nested or stratified structure: Schools were first sampled, and then a fixed number of students was sampled within each school. Base-year data on students came from several sources: (a) a parent survey soliciting information on demographic and academic conditions of the home (usually provided by the mother); (b) a broad-based survey of students' attitudes, behaviors, and aspirations relevant to education; (c) tests of students' achievement in mathematics, science, reading, and social studies; (d) data from two of their teachers (either English or social studies, and either mathematics or science); and (e) data describing schools from principals. Students, teachers, and parents also provided descriptive information about their schools. Most germane to this study, the NELS design gathered data from science teachers on a random half of the sample, sampled by school. For this study, we used data on the same students collected at both the base year (1988) and the first follow-up (1990). Except for the parent survey, similar data were collected at the first follow-up from in-school base-year participants. The NELS design called for teachers in the same subjects to supply data at both waves.

The analytic sample for our previous work on eighth graders was restricted to students with achievement scores, with survey information from students and parents, and with information from teachers (either science or mathematics). Sample selection for this study began with the reduced sample from the Lee and Burkam (1996) study ($n = 18,777$ students). From

this pool, for this study we dropped students who (a) did not participate in the first follow-up, (b) did not have tests scores at Grade 10, (c) were not in the 10th grade during the first follow-up, (d) dropped out of school anytime during the intervening 2 years (even if they returned to school during the 2 years, a *stopout*), or (e) attended more than one school during the 9th and 10th grade years (*transfers*). The application of those data filters resulted in a sample of 12,120 10th graders, almost equally divided by gender (5,907 boys and 6,213 girls).

Besides the two-stage base-year data collection design, NELS also oversampled certain types of middle schools (private schools and schools with high concentrations of Hispanic and Asian students). For this reason, and to adjust for the elimination of certain students who did not fit the panel sample design, we employed the NELS student-level panel design weights for all analyses. These weights compensate for departures from simple random sampling at both time points. Results from this study may thus be generalized to U. S. high school sophomores in 1990.

Measures

Dependent variables. We employed two dependent variables, drawn from the 25-item 10th-grade NELS science test. Similar to our earlier study and based on item content, we created two subtests (life and physical science). Scores on one dependent variable, a 17-item test of physical science achievement, were moderately reliable ($\alpha = .76$). Scores on the second variable, the number correct on an 8-item test of achievement in life science, had modest reliability (Cronbach's $\alpha = .59$). Both are normally distributed continuous variables. We recognize that outcomes with modest reliabilities (resulting from small numbers of items) limited our ability to find relationships. Thus, we argue that relationships that did emerge represent lower bounds for the true relationships.¹

Independent variables. Because of the large sample size and complex nature of our research questions, our analytic models included many of the factors suggested by Oakes (1990). Our primary focus was on gender, with other independent variables considered as covariates. We divided the independent variables into nine sets. Details of construction for all variables used in our models (independent and dependent), psychometric properties of all composites, and the NELS variables from which each variable was drawn, are provided in the appendix.

- *Eighth-grade science achievement.* This set includes two tests, each composed of the number correct on the 9-item life and 16-item physical science subtests collected at Grade 8.
- *Demographic characteristics of students.* These measures include our main independent variable: gender, as well as race/ethnicity and socioeconomic status (SES).
- *Students' overall high school program.* Here, we include items describing the students' high school track placement: academic, vocational, general, or other.

- *Students' coursework in science.* We include several measures of the Carnegie units of physical, life, earth, and general science completed during the first 2 years of high school, drawn from student self-reports.
- *Students' reports on current (10th-grade) science class activities.* This set includes measures of time (hours of weekly homework) and the frequency of particular activities in sciences classes and laboratories. A composite variable measuring *student-active class procedures* includes discussing careers in science, choosing topics to study, and making up methods to solve problems. A *passive-student class procedures* composite includes listening to the teacher lecture, copying the teacher's notes, and reviewing work from the previous day.

Two measures tap the frequency of particular activities in science labs. A measure of *student-active lab activities* includes writing lab reports and conducting one's own experiments. Another measure, *student-passive lab activities*, includes watching the teacher demonstrate an experiment and using books to show how an experiment works.

Another composite measures the frequency of computer use in science for writing reports, collecting data, performing calculations, and modeling science phenomena. A science classroom climate composite includes students' perception of emphasis on: increasing science interest, learning science facts/rules, further study in science, ways to solve science-related problems, and the importance of science to one's own life. One final composite measures student-reported science classroom engagement—including, how often students are asked to show understanding, how often they work hard, and how often they feel challenged.

- *Teacher demographics and qualifications to teach science.* This set includes teachers' self-reports of gender, years of teaching experience, and a composite measure tapping qualifications (certification, undergraduate and graduate training in science, and self-reports of preparation to teach science).
- *Teachers' description of science class structure/grading policies.* Teachers reported on the ability level of the class—academic, advanced, general, or vocational/other; the importance of nonachievement-related behavior for course grades (including attendance, participation, effort); and the importance of absolute versus relative achievement for assigning grades in courses.
- *Science class activities.* This set includes teachers' reports of the percent of class time spent on noninstructional activities; minutes per week the class meets for lab; frequency of student-focused lab activity, including students conducting experiments and writing reports; condition and amount of available lab equipment.

Analysis Methods

Our approach proceeded from descriptive analyses to multivariate regression models. The structural focus of all analyses was on gender. We began with descriptive comparisons between 10th-grade girls and boys, grouping

variables by student demographics, science achievement, students' descriptions of their high schools and their science courses, and information from students' 10th-grade science teachers. Subsequent analyses focused on gender differences in achievement, adjusted for covariates. The final step of our multivariate analyses examined the possibility of interactions between gender and the covariates in the models.

Achievement models. Science achievement models (life and physical science subtests) were estimated using ordinary least squares (OLS) regression (Cohen & Cohen, 1983; Pedhazur, 1982). OLS allows researchers to estimate the unique contribution of each independent variable to explaining variance in the outcome, holding constant other variables in the model. We used OLS regression in a hierarchical format, with predictor variables entered in the same sets in which we grouped them above.

Interactions. The second and third research questions hypothesize *statistical interaction*. The second question suggests that gender differences in science achievement vary by the ability of the student (a gender-by-ability interaction). The third suggests that certain educational practices have *different* effects on boys' and girls' achievement (e.g., a gender-by-lab interaction). Our analytic models thus include not only first-order terms but second-order (or interaction) terms between gender and other independent variables.

Briefly, we provide information on two important issues regarding second-order effects: (a) how we constructed the interactions terms and (b) our approach to identifying significant interactions. We computed a large set of interaction terms, formed as product terms between the gender indicator and other predictor variables (e.g., $X_1 * X_2$, where X_1 = the dummy-coded gender variable, and X_2 = 8th-grade life or physical science achievement). To facilitate comparisons, we standardized all continuous variables (dependent and independent) by transforming them into z scores (mean [M] = 0 and standard deviation [SD] = 1) before using them in our multivariate models. Reported parameter estimates are the *unstandardized* regression coefficients based on these *standardized* predictors.

We estimated the interaction between gender and prior science achievement by explicitly including this cross-product term in our regression models. Although we also searched for evidence of significant gender interactions with all independent variables on the two science achievement tests, the OLS models reported here include only the significant interaction terms.² The absence of a gender interaction from our reported models indicates that there was no statistical evidence for such an interaction (although each was estimated).

Design effects. Because the sampling design for NELS involved cluster sampling—students nested within schools—standard errors associated with means are artifactually reduced, resulting in somewhat inflated significance levels. These design effects, while sizable with simple means, are substantially reduced in multivariate models. Even in multivariate analyses, however, they are not negligible. In order to safeguard against inflated signifi-

cance levels, we report differences as statistically significant only when $p < .01$, rather than the more conventional .05 probability cutoff. This practice is consistent with direct estimates of the magnitude of the design effects for the NELS cognitive tests in multivariate models.

Results

Descriptive Results

Table 1 displays means and percentages, separately by gender, of the variables in our study. Mean differences were tested with either chi-square or t tests, depending on the variable's form. Such a large sample size means that small differences are often statistically significant. Thus, it makes sense to focus on the magnitude of differences as well as their statistical significance. We therefore discuss differences measured in standard deviation (SD) units, or effect sizes.³

Gender differences in achievement. Panel A of Table 1 displays means on the science subtests at Grades 8 and 10. The negligible unadjusted gender difference on the 8th-grade life science achievement test remained intact at the 10th grade. A larger male advantage in 8th-grade physical science achievement ($ES = -.26$) had grown by more than a third at the 10th-grade level ($ES = -.35$). These descriptive results lend support for our first research hypothesis: Gender differences in science achievement remain dependent on subject matter, and the unadjusted male advantage in physical science achievement increases during the first 2 years of high school. On all four science tests, the standard deviation for boys' scores was higher than for girls' scores. Along with the higher average performance of boys in some areas of science achievement, they manifested a wider variability in performance (consistent with the findings of Hedges & Nowell, 1995).

Demographic differences by gender. Not surprisingly, students' demographic differences by gender (Panel B of Table 1) were modest. Among the African-American students, there was a slightly higher percentage of girls than boys, and boys had a slightly higher SES than girls ($ES = -.08$).

Gender differences in curriculum placement and coursework. Although curriculum differences were very small, boys were more likely to be in a vocational or other nonacademic program than girls. Girls were more likely to be in the academic high school program (see Panel C). Completed science courses also show only small gender differences (Panel D). Means here are somewhat misleading, because the distributions of these variables are positively skewed: Many students had earned no science credits in particular areas (e.g., earth science). During the early years of high school, boys and girls accrue the same number of Carnegie units in physical and earth science courses (approximately .5 year of the former and .2 year of the latter). Girls earned more credits in life science ($ES = .15$) and slightly fewer credits in general science ($ES = -.07$). Therefore, the increase in gender differences in physical science achievement in the first 2 years of high school is unlikely to be accounted for by differences in course exposure.

Table 1
Description of Sample

Gender	Male	Female
Unweighted sample sizes	5,907	6,213
A. Student achievement		
Life8 (9 items)	4.90	4.98
(<i>SD</i>)	(1.87***)	(1.79)
Life10 (8 items)	4.87	4.86
(<i>SD</i>)	(1.94***)	(1.80)
Phys8 (16 items)	9.77***	8.95
(<i>SD</i>)	(3.18***)	(2.92)
Phys10 (17 items)	10.31***	9.00
(<i>SD</i>)	(3.70***)	(3.48)
B. Student demographics		
% Black	8.1	9.9***
% Hispanic	8.4	7.7
% Asian	3.1	2.9
SES	0.08***	0.02
(<i>SD</i>)	(0.74)	(0.75)
C. Overall student curriculum		
% Academic program	37.2	39.7**
% General program	40.7	43.1
% Vocational program	9.8***	6.6
% Other (nonacademic)	12.3***	10.6
D. Science class, Carnegie units		
Physical science	0.55	0.54
(<i>SD</i>)	(0.50)	(0.51)
General science	0.28**	0.25
(<i>SD</i>)	(0.45)	(0.44)
Life science	0.82	0.88***
(<i>SD</i>)	(0.39***)	(0.36)
Earth science	0.22	0.21
(<i>SD</i>)	(0.37)	(0.38)
E. Students' reports on science class activities		
Time on homework, hours weekly	3.01	3.31***
(<i>SD</i>)	(3.15)	(3.15)
Active class	0.02***	-0.15
(<i>SD</i>)	(1.01***)	(0.85)
Passive class	-0.06	0.07***
(<i>SD</i>)	(1.01***)	(0.94)
Active lab	0.03***	-0.13
(<i>SD</i>)	(1.02***)	(0.90)
Passive lab	-0.04	-0.05
(<i>SD</i>)	(0.98)	(0.97)
Climate	-0.03	-0.01
(<i>SD</i>)	(0.99)	(0.98)
Computer	0.04***	-0.12
(<i>SD</i>)	(1.05***)	(0.74)
Engagement	-0.03	0.04***
(<i>SD</i>)	(1.00**)	(0.96)

Table 1
Description of Sample (continued)

Gender	Male	Female
F Science teacher characteristics		
% Female teacher	37.8	39.8
Years of teaching	14.6	14.1
(SD)	(8.32)	(8.40)
Teacher preparation	-0.02	0.02
(SD)	(1.02)	(0.99)
G. Science teachers' reports on class track/grading policies		
% Academic science	43.8	50.8***
% Advanced science	13.6	11.6
% General science	38.5	35.1
% Vocational/other nonacademic	4.1	2.5
Grading on achievement	0.02	0.04
(SD)	(1.01)	(1.03)
Grading on behavior	-0.02	0.00
(SD)	(1.00)	(0.99)
H. Science teachers' reports on class activities		
Lab time, minutes weekly	64.3	63.7
(SD)	(42.0)	(39.8)
Student-active lab	-0.02	0.00
(SD)	(1.00)	(0.97)
Lab equipment	0.07	0.03
(SD)	(0.91)	(0.96)
Noninstructional class time	-0.02	-0.07
(SD)	(0.99**)	(0.93)

Note: All continuous variables transformed to z scores ($M = 0$, $SD = 1$) in multivariate models. Differences tested for significance: ** $p < .01$, *** $p < .001$.

Although our final analyses controlled for these measures of science coursework, an exploration of coursetaking patterns revealed five disjoint groups that comprised nearly three quarters of the students during the first 2 years of high school: 36.3% reported a year of life science and a year of physical science; 11.7% reported a year of life science and a year of earth science; 10.6% reported a year of life science and a year of general science; 8.0% reported a year of life science only; and 4.7% took no science. The remaining 28.7% reported some other coursework pattern.

Gender differences in science class experiences. Although consistently small, gender differences in science class activities are larger than all other measures except for achievement (Panel E). Compared to boys, girls reported spending more time on science homework ($ES = .10$) and less time in *active* classrooms (i.e., where students discussed careers in science, chose their own topics to study, and made up methods to solve science problems, $ES = -.17$). Girls reported spending more time in *passive* classrooms (i.e., where students listened to lectures, copied notes, and reviewed the previous

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day's work, $ES = .13$) and less time in active lab activities (i.e., where students conducted their own experiments and wrote lab reports, $ES = -.16$). Boys and girls were similar in the time they reported spending in *passive labs* (i.e., where students watched the teachers conduct experiments or used a book to show how an experiment worked) and in their descriptions of the climates of their science classrooms. Boys reported more computer usage ($ES = -.15$), while girls reported higher engagement in their science classes ($ES = .07$).⁴

Gender and science teachers' reports about classes. In the 10th grade, boys' and girls' science teachers have similar characteristics (about 40% were women, with an average 14 years of teaching experience, and comparable professional preparation—see Panel F).⁵ Although boys' and girls' teachers reported similar grading policies, their reports of the *track* of their science courses were not comparable by gender (Panel G). Girls were more likely than boys to be taking an academic science course. Note that all measures in Panels F, G, and H, because they were provided by teachers, were defined for only a random half of the student sample.

Despite the gender differences in student-reported science class (Panel H), the teachers' reports of class activities were gender-neutral. Teachers reported approximately one hour spent on lab activities each week; boys and girls experienced the same amount of active laboratory experience. This contradicts the girls' own reports, because they claimed to be spending less time than the boys on active lab (Panel E). This may reflect the possibility that girls often felt they were passively involved, even during hands-on activities—perhaps their male lab partners were the ones performing the experiments. Teachers also reported comparable lab equipment for boys and girls and comparable time spent in class on noninstructional activities.⁶

Summary of descriptive results. The results in Table 1 offer some support for the first hypothesis: Gender differences in 10th-grade science achievement are dependent on subject matter. There was a moderate male advantage in physical science achievement ($ES = -.35$ —magnified since 8th grade) but no discernible differences in life science. This gender-based achievement disparity was more than twice the magnitude of any other gender differences considered in this study. As coursetaking disparities were quite small, they were unlikely to account for differences in learning. There was considerable evidence from the students that girls had different science classroom experiences than boys. Except for the description of the science track, the teachers' reports did not support a disparity by gender. Consequently, gender differences may be a combination of *differences in experience* and *differences in perception*.

Preliminary Multivariate Models: Gender-by-Ability Interactions

Our second research question asks whether the gender gap is constant across different levels of students' ability. These gender-by-ability interactions are displayed graphically in Figure 1. The results are from four regression models: Gender, race/ethnicity, SES, and prior ability are predic-

tors of achievement in life and physical science at the 8th and 10th grades for the same students. Prior ability for the base-year regressions was tapped by a measure of science course grades from the previous 2 years. A longitudinal measure of prior ability was available for the 10th grade achievement regressions: the corresponding NELS subtest at Grade 8.

The similarity in life science achievement scores by gender is evident from Graphs A and C of Figure 1. The 8th-grade male advantage in physical science achievement is clear in Graph B. The male advantage in this area stabilized over time (compare Graphs B and D). These results suggest a negative response to our second research question. For 10th graders, there emerged a gender-by-ability interaction in life science achievement (the lines cross in Graph C). Gender differences favored boys among students of higher ability, but less able girls scored higher than their male counterparts. The male achievement advantage in physical science, which at 8th grade was larger for most able students, appeared to have stabilized across ability levels by Grade 10 (Graph D).

There is no simple answer to the question of whether the gender gap in physical science achievement had increased during the first 2 years of high school. The unadjusted gender differences described in Table 1 suggested a wider disparity (the 8th-grade difference of $ES = -.26$ grew to a 10th-grade difference of $ES = -.35$). The graphs in Figure 1 (adjusting for student background) suggested the 10th grade disparity had stabilized across

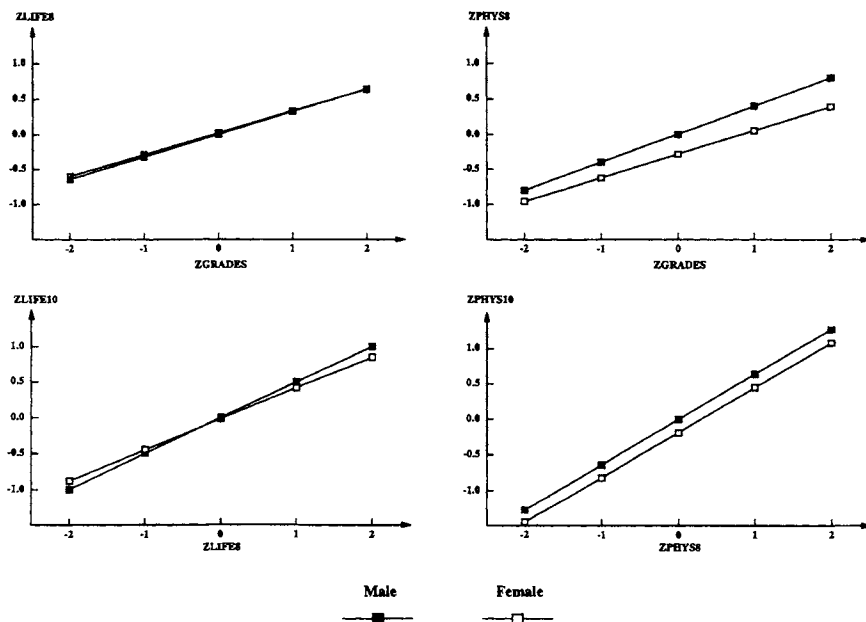


Figure 1. Gender and science achievement

Hence, at some ability levels the gender difference had increased (e.g., among less able students); at others (e.g., among more able students) the gender difference had decreased slightly.

These graphs suggest a troubling pattern of gender differences in science achievement as students moved through the early high school years. The gender gap in life science achievement changed from slight differences to differences favoring boys among high achievers. Gender differences in physical science achievement changed from a substantially larger male advantage among high achievers to a uniform gap 2 years later for all ability levels. These graphs suggest that boys' advantage over girls in physical science achievement began as gender differences most pronounced among the more able students and stabilized over early adolescence. What in the high school experience, and particularly in science classes, results in these male advantages in science performance for adolescents in their first 2 high school years? Our remaining analyses investigated this question.

Multivariate Analyses: Model Structure

Results from Table 1 and Figure 1 indicate that high school science subject matter was related to gender differences in achievement (Research Question 1) and students' ability level (Research Question 2). The analyses, the results of which are displayed in Tables 2 and 3, investigated why this might be so. In particular, we investigated whether these differences were mediated by certain characteristics and practices of science classrooms: especially hands-on, active learning environments. Analyses for each subject involved identical hierarchical OLS models (Cohen & Cohen, 1983). We entered variables in groups, as defined in Table 1. The order of entering these groups was based on a temporal sequence.

First we considered the impact of student demographics (Models 1 and 2 in Table 2). Subsequent regression steps included overall student curricular programs (Model 3) and completed coursework in science (Model 4). The next steps—our special focus—added classroom activities reported by students (Models 5 and 6) and reports by teachers about themselves and their class activities (Model 7). To allow comparison across effects on the two science tests (and due to our coding decisions), all effects displayed in Tables 2 and 3 are in *SD* units.

We considered all variables in the full set described in Table 1 in the initial analyses, but some were not significantly related to either life or physical science achievement in the full models. To reduce the complexity of these models, such variables were eliminated in the final models. One such measure was students' report of the frequency of passive class procedures (listening to teacher lecture, copying teachers' notes, and reviewing work from the previous day). Other variables we omitted involved certain teacher characteristics and teacher reports (the final category). For example, in these multivariate models, the gender of the science teacher, his or her teaching experience, and teacher preparation were unrelated to student performance. Similarly, neither teachers' grading policies, time spent

in lab, nor lab equipment issues were related to student learning in either science subject. None of these were present as predictors in the final models. The teachers' report of the several difficulty levels in their science classes (Panel G of Table 1) were collapsed into three designations (and two dummy variables): advanced and general, each compared to academic as the reference group.

Multivariate Analyses of Physical Science Learning

Student demographic differences. Results in Model 1 of Table 2 indicate that student demographic characteristics were strongly associated with physical science achievement. Boys did modestly better than girls ($b = -.19$), and Black and Hispanic students scored below White students ($b = -.32$ and $-.19$, respectively). Higher SES students were also advantaged ($b = .21$). These differences were net of 8th-grade physical science achievement (a large effect, $b = .56$), so we interpret these as demographic effects on physical science learning, rather than achievement status. There is no evidence of a gender-by-ability interaction in physical science. Reflecting Graph D of Figure 1, the gender gap was constant across ability levels.

There were, however, other gender interactions (Model 2). All interactions had a dual interpretation. For example, the significant female-by-Black interactions suggest that (a) the Black-White difference is distinct for males and females or equivalently (b) the gender difference is distinct for Whites and Blacks. The first-order coefficient for the Black-White gap is for males only; the first-order coefficient for gender is the gender gap for Whites only. Focusing on the latter interpretation, we see that the gender gap in physical science achievement is predominantly among White, Hispanic, and Asian students (gender gap = $-.21$, the first-order effect for gender). The gender gap among Black students is negligible (gender gap = $-.04 = -.21$ [the first-order effect] + $.17$ [the interaction effect]).

In addition, higher SES girls were more advantaged than higher SES boys on this outcome (i.e., SES had a larger effect for girls than for boys, $b = .24$ versus $.19$, respectively). Furthermore, this gender-by-SES interaction implies that (a) for White, Asian, and Hispanic students there is a male advantage throughout the range of SES but the male advantage decreases as SES increases and (b) for Black students the male advantage may disappear as SES increases. The inclusion of other school and classroom factors tended to *increase* many of these differences. Gender and ethnic differences were largest in the final step of the model, although the gender gap among Black students was negligible.

Effects of student curriculum and science course credits. Students' placement in any high school curricular program (or track) other than an academic one was associated with reduced learning in physical science (Model 3). Additional coursework in physical, life, or earth science was positively linked with students' physical science learning, but more coursework in general science was negatively linked with learning ("general" science courses often serve as alternatives for the noncollege bound students). There

Table 2
10th-Grade Physical Science Learning

Model	1	2	3	4	5	6	7
Student demographics							
Female	-.19***	-.21***	-.23***	-.24***	-.25***	-.25***	-.25***
Black	-.32***	-.41***	-.41***	-.43***	-.44***	-.43***	-.43***
Hispanic	-.19***	-.19***	-.19***	-.18***	-.19***	-.18***	-.19***
Asian	.01	.01	.00	.00	.00	.00	.01
SES	.21***	.19***	.15***	.13***	.13***	.13***	.12***
8th-grade ach	.56***	.56***	.53***	.52***	.51***	.51***	.50***
Female x ach	-.01	-.02	-.02	-.02	-.02	-.02	-.02
Female x Black		.17***	.17***	.18***	.19***	.19***	.18***
Female x SES		.05**	.06**	.07**	.07**	.06**	.07**
Overall student curriculum							
General program			-.15***	-.14***	-.13***	-.13***	-.12***
Vocational program			-.32***	-.28***	-.27***	-.27***	-.26***
Other (nonacademic)			-.33***	-.29***	-.28***	-.28***	-.27***
Science class, Carnegie units							
Physical science				.08***	.08***	.08***	.08***
General science				-.03**	-.02	-.02	-.01
Life science				.06***	.05***	.05***	.05***
Earth science				.04***	.04***	.04***	.04***
Students' reports on science class activities							
Time on homework					.02	.02	.02
Active class					-.05***	-.05***	-.04***
Active lab					.03***	.01	.01
Passive lab					-.02**	-.02**	-.03**
Computer					-.03**	-.03**	-.02**
Climate					.06***	.06***	.05***
Engagement					.00	.00	.00
Female x act lab						.05**	.05**
Science teachers' reports on class track/activities							
In science sample							-.01
Advanced science							.14***
General/vocat/other nonacad							-.07**
Noninstructional class time							-.01
Student-Focused lab							.05***
Constant	.206***	.216***	.360***	.348***	.348***	.349***	.354***
R2	.472***	.473***	.486***	.497***	.503***	.504***	.506***
Change R2	.472***	.001***	.013***	.011***	.005***	.001***	.002***

p < .01, *p < .001.

was no evidence of differential effects of student curriculum or coursework by gender on learning in physical science.

Effects of students' reports of class activities. Important findings concern students' experiences in the laboratory component of their science classes; our findings are consistent with our study of 8th-grade physical science

achievement on the same students (Lee & Burkam, 1996). It is noteworthy that although additional active lab experiences, as reported by students (writing lab reports and conducting their own experiments), did not enhance 10th-grade boys' learning in physical science, these activities were positively correlated with 10th-grade girls' learning ($b = .01 + .05$, or .06, Model 6). There is a dual interpretation of this interaction: (a) The effect of hands-on lab seems to differ for males and females, and (b) the moderate gender gap favoring males may shrink in the presence of additional hands-on lab work (at average levels of lab work the gender difference is $-.25$, at 1 *SD* above the mean the difference is $-.20 = -.25 + .05$, a 20% reduction).

On the other hand, computer use in science class, active class procedures, and passive lab activities were negatively associated with learning in physical science.⁷ Increased time on homework and increased classroom engagement were not significantly related to learning. Conducive to physical science learning (regardless of gender) was a climate that emphasized increasing science interest, learning science facts/rules, further study in science, multiple ways to solve science problems, and the importance of science to students' lives.

Effects of teachers' reports of class track/activities. An important finding concerns the effect of the teacher-reported frequency of student-focused lab (conducting experiments and writing reports); more frequent use of these activities in science classrooms positively contributes to *all* students' learning (regardless of gender). It is important to note that the teachers' report of student-focused lab had an effect independent from (and equal in size to) the students' report. Together, these two effects reinforce the importance of frequent hands-on lab activities for all students (noted by the effect of the teachers' report), with particular importance for girls (evidenced by the differential effect of the students' report). We also found that students in advanced classes outperformed their academic class counterparts ($b = .14$), while the academic class students only slightly outperformed students in general-level classes ($b = -.07$). Increased class time devoted to noninstructional activities had no significant effect on learning in this multivariate model.

Summary of effects on physical science learning. Gender differences in physical science learning favored boys in the first 2 years of high school. This gender gap, moderate in size, was constant across ability levels, even after controlling for physical science understanding at high school entry. There was no gender difference in physical science learning among Black students, although the overall level of learning for Black students was well below their White peers. Most important, and addressing our third research question, is the finding that additional student-focused, hands-on lab experiences were beneficial for all students' learning in physical science, but especially so for girls.

Multivariate Analyses of Life Science Learning

Student demographic differences. Table 3 displays results of an almost identical analytic model to that shown in Table 2 for physical science. The

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exception is the outcome measure—10th-grade achievement in life science—and the ability control—8th grade life science performance. Here the gender differences were substantially smaller than in physical science and favored males among students of average and above-average ability and females among the less able students (as Graph C in Figure 1 showed). Racial/ethnic differences were smaller in life science than physical science learning, but higher SES students exhibited an advantage on both outcomes.

Table 3
10th-Grade Life Science Learning

	1	2	3	4	5
Student demographics					
Female	.00	.01	-.03	-.05**	-.05**
Black	-.29***	-.29***	-.29***	-.28***	-.29***
Hispanic	-.14***	-.13***	-.12***	-.13***	-.13***
Asian	.03	.02	.03	.03	.01
SES	.23***	.19***	.16***	.16***	.15***
8th-grade ach	.44***	.42***	.40***	.38***	.38***
Female x ach	-.08***	-.08***	-.08***	-.07***	-.07***
Overall student curriculum					
General program		-.21***	-.18***	-.16***	-.15***
Vocational program		-.41***	-.35***	-.32***	-.31***
Other (nonacademic)		-.43***	-.37***	-.35***	-.33***
Science class, Carnegie units					
Physical science			.02	.02	.02
General science			-.05***	-.04***	-.03***
Life science			.11***	.10***	.10***
Earth science			.01	.01	.01
Students' reports on science course activities					
Time on homework				.02	.02
Active class				-.07***	-.06***
Active lab				.01	.01
Passive lab				-.01	-.01
Computer				-.05***	-.05***
Climate				.09***	.09***
Engagement				.03**	.03**
Science teachers' reports on class track/activities					
In science sample					-.06**
Advanced science					.19***
General/vocat/other nonacad					-.05
Noninstructional class time					-.05***
Student-focused lab					.05***
Constant	.116***	.299***	.274***	.271***	.287***
R2	.268***	.292***	.307***	.322***	.328***
Change R2	.268***	.024***	.015***	.015***	.006***

** $p < .01$, *** $p < .001$.

We remind readers that this test has fewer items and consequently is less reliable than the physical science subtest. This might account for the smaller effects in life science than in physical science.

Effects of student curriculum and science course credits. Identical to physical science, student enrollment in a nonacademic high school track is linked with lower life science learning. Also identical to the results in Table 2, additional coursework in physical, life, or earth science increased students' understanding in life science, and coursework in general science was negatively associated with learning in this area. Nor did we detect evidence of differential effects of overall curriculum or coursework by gender on this outcome.

Effects of students' reports of class activities. Laboratory experiences (active or passive) were not associated with life science learning, as they were for physical science. Increased student engagement and increased climate of science emphasis in science classes, however, were associated with increased learning in life science. In addition, an increase in computer use in science classes, as well as active science class procedures, was associated with *decreased* student learning in both physical and life science (see Note 7). Time spent on homework was not associated with life science learning.

Effects of teachers' reports of class track/activities. Once again we see that the teachers' reports of the frequency of lab activities such as conducting experiments and writing reports positively contributed to all students' learning in life science. As in physical science learning, advanced science class students learned more than their counterparts in academic classes in life science. Devoting more class time to non-instructional activities had a small negative effect on learning in the life science area. In physical science (Table 2), we had evidence from both the students' and teachers' reports of the efficacy of active, hands-on laboratory experiences. In life science, the only evidence for the benefits of lab work that actively involves students comes from teachers' reports.

Summary of effects on life science learning. Gender differences in science achievement at 10th grade were substantially smaller in life than physical science learning and favored males among students of average and above-average ability. Although the evidence in life science was more modest than in physical science, student-focused, hands-on lab experiences were beneficial for all students' learning. There does not appear, however, to be a differentially larger effect of such experiences for girls in the life sciences, as is the case for learning in physical science.

Discussion

Revisiting the Research Questions

Gender and science subject matter. Our first research question centered on whether gender differences in science achievement for students early in

high school are related to the subject matter tested. This study has confirmed such a differentiation: Male high school sophomores are moderately advantaged, compared to their female counterparts, in learning physical science. Although there are no substantial gender differences in life science when students enter high school, by the end of their sophomore year there is a small but statistically significant interaction between gender and prior achievement resulting in a male advantage in this science subject among students of average and above-average ability. Therefore, gender differences are differentiated by science subject matter, but they have become identical in direction: Male students are favored in both subject areas. Our findings underline the importance of even small gender differences in achievement highlighted by Hedges and Nowell (1995): Small mean differences when combined with larger variability among males result in a large underrepresentation of females in the upper tail of the ability distribution from which the future scientists will be drawn.

Gender, science achievement, and ability. Our second research question asked whether gender differences in science learning for students early in high school are related to ability. Because earlier findings had indicated that by the end of the 8th grade the male advantage in physical science is largest for the most able students, we hypothesized that this gender-by-ability interaction would remain (or grow) as students moved into high school. Our hypothesis was not confirmed in physical science, where the gender gap favoring 10th-grade males is not related to ability. Rather, for students of all ability levels, by the end of the sophomore year there is a stable male advantage in physical science achievement. Interestingly, an ability-differentiated gender difference in life science, which is not typical of these students as 8th graders, is evident by the sophomore year. More able 10th-grade boys are outperforming their female counterparts in life science. This leads us to predict that this wider gap in life science achievement among the more able students will spread throughout the population by the end of their high school career.

Gender, science achievement, and laboratory activities. Most solutions proposed to narrow the gender gap in science performance and persistence target girls' lack of science experience, or opportunity to learn science. Lack of encouragement from home and low exposure to science often result in diminishing both knowledge and commitment to science for both genders (Simpson & Oliver, 1990). To increase girls' confidence, performance, and interest in science, the major reform that advocates call for is increasing the emphasis on hands-on science instruction in schools (AAUW, 1992; Mason & Kahle, 1989; Kahle & Rennie, 1993; Lee & Burkam, 1996; Simpson & Oliver, 1985; Spector & Gibson, 1991; Stage, Kreinberg, Eccles, & Becker, 1987). In one study examining schools with favorable records of female enrollment in Advanced Placement courses in mathematics and science, Casserly (1980) outlined the components of teaching especially encouraging to girls, such as cooperative rather than competitive motivational techniques (pitting students against each other), less public drill instruction, more

hands-on learning, problems with practical implications and opportunities for creative solutions, and active, open-ended learning situations.

Another suggestion is to increase the interest value (i.e., personal relevance) of science experiments. One study found that such interest enhancements are particularly effective for girls (Martinez, 1992). Boys were more attentive to aspects of experiments that elicited perceptions of control, whereas girls paid more attention to social dimensions. Girls affirmed such statements as, “This experiment helped us work as a team” and “My partner and I helped each other more than usual.” The author suggested that the interest appeal of experiments may be related to attitudes and future decisions regarding students’ courses of study and career choices. Attitudes toward laboratory activities in particular, and science in general, can be shaped by choice and modification of curricular materials—specifically, procedures for science experiments (Martinez, 1992).

Do students’ experiences in the laboratory component of their high school science classes influence science learning? Posing this question reflected our interest in whether the character of science instruction in classes and laboratories had differential effects on girls’ and boys’ science learning. Our results provide empirical support for the importance of this instructional construct.

Hands-on laboratory experiences, where students do experiments themselves, are linked with increased learning in both subjects. Although students and teachers tend to disagree as to the amount of hands-on lab work—teachers describe more student hands-on work than students, or teachers *remember* more than students (see Note 6)—in physical science, these sorts of activities have particular (and positive) importance for girls’ learning—engaging in them is related to a reduced gender gap in physical science learning. Even at reasonable levels of hands-on lab work (1 *SD* above the mean), both student-reported and teacher-reported time on lab is associated with a gender gap reduced by 20%. Given the relatively low average levels of hands-on lab work to begin with, increasing the time spent on such practices should be a worthy and attainable goal.

In addition, our results underline the importance of classroom climate, particularly one that is strongly focused on science: promotion of interest in the subject and encouragement of advanced study of it, a focus on the content and process of science, and a push toward relating science to real-life questions and problems. Students in science classrooms with such climates learn more in both subjects. These classroom climate effects are undifferentiated by gender; everyone learns more in such classes.

Implications of Our Findings

Why is this study important? Very few, if any, members of modern society would discount the importance of science in contemporary life, nor would many argue that school performance in this subject is unimportant to young people’s educational and professional futures. In the last decade of the 20th century, when many facets of modern life are less differentiated by gender

than they have been, it is discouraging for us to report that girls are still learning less science than boys. It is even more discouraging to find that the gender gap favoring boys appears to increase as students move through the educational system. This suggests that schools have an active role in gender stratification, rather than simply reflecting societal influences related to gender.

The importance of our findings is associated with their source. Our study employs a strong data source, with longitudinal information on a large and nationally representative sample of U. S. students as they move out of the middle grades and into high school. The representativeness of the sample and the fact that our conclusions are drawn from information on the same students as they move through the educational system suggest that these results cannot be discounted. Quite simply, our findings are generalizable to U. S. secondary schools and students in this decade.

Educational experiences in high school. We begin and end with some obvious conclusions about the stability of the female disadvantage in science. The focus of our study is on how such gender stratification in science performance can be addressed. In our analyses, we considered a wide array of factors that are related to students' learning in science. We included classic measures of personal characteristics of students and families (race, ethnicity, social class, and ability) that are necessary components for any study with learning as an outcome (Oakes, 1990). Although our findings in this area are substantial and interesting, we do not suggest that our educational system can have much influence on these effects (at least directly). Rather, we concentrate our concluding comments on policy areas that educators can change, particularly instruction.

The substantive focus of our literature review, analysis, and discussion is on students' experiences inside the high schools they attend. The consideration here has been on three hierarchically structured elements of high school students' educational experiences: track level, course-taking, and experiences within their science classes. Our findings about track placement, not new but strong, point out that students in the academic or college-preparatory track learn more science. Although the importance of such findings should not be discounted, tracking effects on learning have been documented elsewhere (Oakes, 1990). They are generally unrelated to the issue of gender differences in learning. Our descriptive results indicated that there are very small differences favoring girls' enrollment in the academic track.

A common explanation for gender differences in high school students' learning in science and mathematics has focused on the courses they choose, with the argument that girls choose fewer of the "right" courses. According to this explanation, the gender difference in learning should shrink after controlling for coursework. We found minimal evidence that girls' science coursetaking is distinct from boys' during the first 2 years of high school: Girls did complete slightly more Carnegie units of life science and slightly fewer units of general science, but they did complete the same

number of units in physical and earth science. Furthermore, controlling for coursework did not shrink gender differences in learning. In fact, significant gender differences in life science learning did not emerge until we controlled for coursework. Thus, we conclude that the standard “course hypothesis” explanation, at least during the first 2 years of high school, is not a valid explanation for gender difference in science achievement. We are currently investigating this hypothesis using the NELS:88 transcript data gathered over the full 4 years of high school.

The importance of instruction on learning. The major substantive findings in this study have important practical implications for schools’ efforts to increase science learning for all students. These findings are centered in the area of science instruction. The NELS database is rich in reports from both students and teachers about their high school science classes. Our multivariate models provide solid evidence that students learn more in science classes that include regular laboratory activities, where students are actively engaged in such activities as writing up lab reports and performing their own experiments (rather than merely watching the teacher do them). Teachers’ reports about the laboratory components of their courses that focus on the frequency of such activities—students doing the experiments and writing up reports on them—have similar and independent positive relationships to learning in both subjects. Our results support the saliency to learning of a classroom climate focused on the importance of science, its applicability to life, and the way science problems are solved. Furthermore, our results suggest that adopting these strategies may reduce the gender gap in physical science learning.

Important negative and nonfindings. The importance of these elements of science instruction in high schools is underlined by the more modest relationships to learning in science of other classroom elements. Some seemingly beneficial activities either have no effect or actually detract from learning. For example, the total amount of time spent in laboratory activities in a given week, as reported by science teachers, is unrelated to learning. Given our results documenting the importance of the character of laboratory experiences, it seems reasonable that more would be better. At least as measured in the NELS survey through teachers’ reports, that is not the case.

Also unrelated to learning are the availability and condition of laboratory equipment. We were surprised that these two seemingly important elements of high school science classes—time spent on lab and equipment—are not related to learning. Students’ active involvement in lab work is more critical than the quantity of lab work or quality of the equipment.

It could be that other statistical controls, related to these conditions and to learning, have explained away these effects, although bivariate results also suggest little impact of these elements. It could also be that measurement issues are important: These measures are particularly unreliable in this large survey format. Why weak measurement would be particularly important here, however, and not in other items describing science classrooms and instruction, is unclear.

We were surprised at the modest size of the relationship with learning of the proportion of class time devoted to activities other than instruction, although its direction (negative) is reasonable. Especially noteworthy and surprising are the negative relationships of computer usage in science classes on learning in both subject areas (see Note 7). Although this negative association is not differentiated by gender (i.e., computer usage is equally detrimental for boys and girls), it suggests that computers in science may be employed for the wrong reasons or that computer activity is used as a substitute for solid instruction and active investigation. Our results indicate that a blanket call for “more computers in science” is unwarranted. Rather, the use of computers in high school science classrooms should be carefully scrutinized.

Because we have assumed that qualifications for teaching science at the high school level are perhaps more rigorous than in other subjects (or maybe more difficult to find in the high-school teacher population), we were surprised by our findings that teachers’ qualifications and teaching experience are unrelated to students’ learning, at least as these variables were measured and analyzed. Neither is teacher gender a factor in students’ learning (for either gender). Less than 40% of high school science teachers are female, and, in general, these teachers are well prepared and highly experienced. In our multivariate models. However, these admittedly important characteristics of the high school science teaching force are unrelated to learning. These nonfindings are noteworthy.

In general, readers and researchers alike should be suspicious of studies that proclaim nonfindings as important. All too often, the research design (particularly, the sample size) is insufficient to allow modest effects to show themselves. In this instance, the issue of insufficient statistical power (Cohen & Cohen, 1983) is probably not a problem. With a large sample size (over 12,000 students with their many thousands of teachers and classrooms), finding significant coefficients is not difficult, even if measures are blunt (as some certainly are here). In fact, Tables 2 and 3 display many significant effects of small magnitude. Thus, we contend that the noneffects discussed here are substantively meaningful.

Instructional change in high school science classrooms. Our bottom line conclusions center on the character of instruction in science. This study provides solid evidence that regular, hands-on experimentation has importance for all students’ learning. High schools and their science teachers need to increase laboratory experiences that involve rigorous experimentation that students do themselves, are required to write up, and from which they should draw conclusions. Because the NELS data come from surveys rather than observations—passive and derivative measures of instruction rather than first-hand and possibly more objective measures—we cannot say exactly why these activities would have particular importance for girls’ learning, only that they do. One speculation subscribes to an old stereotype that may still hold true: Girls may not engage in the informal science-related experiences outside of the classroom—activities such as investigating me-

chanical objects to see how they work—with the same frequency as boys. Hence, such experiences in the classroom are all the more critical for girls' understanding.

Although these findings seem obvious in one sense (many have been calling for this type of science instruction for a long time), they are also troubling. Why aren't all high school science classes structured this way? From a data point of view, why is this even a variable? Our evidence about the importance of the climate of science classrooms is also troubling for the same reasons. Why aren't all high school science classes aimed at increasing students' interest in the subject? Why don't all these classes emphasize learning the content of science and how to solve problems in it? Why don't all science courses relate their subject matter to real-life happenings and understandings? We present evidence that these things really matter.

Clearly, it is easier to identify what seems to matter for students' learning in science, and even to focus on elements of instruction that have particular saliency for girls, than it is to change the character of instruction in science classes in high schools. The evidence from this study indicates a clear direction for the reform of high school science instruction, but we frankly admit it provides very little insight about how to move teachers in that direction.

APPENDIX

Description of Construction of Variables Used in the Study

I. Student Achievement:

Life8—Subscore from the NELS science achievement test, Grade 8, number correct out of 9 items, z score ($M = 0$, $SD = 1$, alpha-reliability = .50).

Life10—Subscore from the NELS science achievement test, Grade 10, number correct out of 8 items, z score ($M = 0$, $SD = 1$, alpha-reliability = .59).

Phys8—Subscore from the NELS science achievement test, Grade 8, number correct out of 16 items, z score ($M = 0$, $SD = 1$, alpha-reliability = .68).

Phys10—Subscore from the NELS science achievement test, Grade 10, number correct out of 17 items, z score ($M = 0$, $SD = 1$, alpha-reliability = .76).

II. Independent Variables:

A. Measures describing student demographics

1. *Female*—Gender of student; 1 = Female, 0 = Male (recoded from SEX).
2. *Black*—Race/ethnicity of student; 1 = Black, 0 = Other (recoded from RACE).
3. *Hispanic*—Race/ethnicity of student; 1 = Hispanic, 0 = Other (recoded from RACE).
4. *Asian*—Race/ethnicity of student; 1 = Asian, 0 = Other (recoded from RACE).
5. *SES*—Socioeconomic status (composite includes parents' education, father's occupation, family income, and several educationally-oriented household possessions [from F1SES]) z score ($M = 0$, $SD = 1$).

B. Measures describing students' high school curriculum

1. *General*—Student-reported description of overall high school program, 1 = "General," 0 = "Other" (recoded from F1HSPROG), fixed reference group: "Academic."

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2. *Vocational*—Student-reported description of overall high school program, 1 = “Vocational,” 0 = “Other” (recoded from F1HSPROG), fixed reference group: “Academic.”

3. *Other*—Student-reported description of overall high school program, 1 = “Other” or “Don’t Know,” 0 = “Other” (recoded from F1HSPROG), fixed reference group: “Academic.”

C. Measures describing students’ science class (Carnegie units)

1. *Physical science*—Sum, Carnegie units, Grades 8-10, student reported [includes physical science (F1S23B), chemistry (F1S23E), principles of technology (F1S23F), and physics (F1S23G)], z score ($M = 0$, $SD = 1$).

2. *General science*—Sum, Carnegie units, Grades 8-10, student reported [includes general science (F1S23A) and other (F1S23H)], z score ($M = 0$, $SD = 1$).

3. *Life science*—Sum, Carnegie units, Grades 8-10, student reported [includes biology only (F1S23C)], z score ($M = 0$, $SD = 1$).

4. *Earth science*—Sum, Carnegie units, Grades 8-10, student reported [includes earth science only (F1S23D)], z score ($M = 0$, $SD = 1$). Note: The construction of these course variables involved a two-step procedure in order to ensure consistent and reasonable responses.

(a) Students whose *total* units of completed science (sum of the above four categories) exceeded 3 years (3.5 through 16) were deemed to have given problematic information. Although 2 years of science would, in general, be the maximum number of years of science available for students during the first 2 years, we chose to use 3 as the cutoff to allow for students in accelerated science programs who may have elected additional coursework, as well as to allow for the fact that the above categories do not necessarily reflect disjointed course work. Because it is impossible to tell which of the student responses are faulty, we replaced all of their grouped scores by missing values. The general effect of this adjustment on correlations between course-taking and performance (on the 10th-grade achievement tests, physical and life science) is an *increase* in magnitude. This is expected because of the reduction in noise.

(b) In order not to lose the cases recoded to missing from Step 1, we replaced those missing values with group mean scores. This was done by a three-way breakdown: *gender* by (*overall*) *10th-grade science achievement quartile* by *high school program* (*general, academic, vocational/ technical, other, or “don’t know”*). Individual missing values on the five grouped scores were replaced by the corresponding mean scores. Overall, about 7% of the sample received imputed values in Step 2 of this process.

D. Measures describing students’ reports on science class activities

1. *Hwtime*—Student-reported weekly hours of homework (includes science homework in school [F1S36C1] and science homework out of school [F1S36C2]), z score ($M = 0$, $SD = 1$, alpha-reliability = .484).

2. *Actclass*—Student-reported frequency of active class procedure (composite includes discussing careers in science [F1S29M]; making own choice of science topics to study [F1S29B]; and making up methods to solve science problems [F1S29F]), z score ($M = 0$, $SD = 1$, alpha-reliability = .577).

3. *Passclass*—Student-reported frequency of passive class procedure (composite includes listening to teacher lecture [F1S29L]; copying teacher’s notes [F1S29C]; reviewing work from previous day [F1S29A]), z score ($M = 0$, $SD = 1$, alpha-reliability = .448).

4. *Actlab*—Student-reported frequency of active lab procedures (composite includes writing lab reports [F1S29D]; conducting own experiments [F1S29G]), z score ($M = 0$, $SD = 1$, alpha-reliability = .372).

5. *Passlab*—Student-reported frequency of passive lab procedures (composite includes watching teacher demonstrate science experiment [F1S29N]; using books to show how experiment works [F1S29E], z score ($M = 0$, $SD = 1$, alpha-reliability = .495).
6. *Computer*—Student-reported frequency of computer use (composite includes using computers to write science reports [F1S29H]; using computers for collecting science data [F1S29I]; using computers for science calculations [F1S29H]; using computers for science models [F1S29K], z score ($M = 0$, $SD = 1$, alpha-reliability = .792).
7. *Climate*—Student-reported science course climate (composite includes emphasis on: increasing science interest [F1S30A]; learning science facts/rules [F1S30B]; further study in science [F1S30C]; ways to solve science problems [F1S30D]; importance of science to life [F1S30E], z score ($M = 0$, $SD = 1$, alpha-reliability = .814).
8. *Engage*—Student-reported engagement in science course (composite includes how often asked to show understanding in science [F1S26D]; how often work hard in science class [F1S27D]; how often feel challenged in science class [F1S28D], z score ($M = 0$, $SD = 1$, alpha-reliability = .651).

E. *Measures describing science teacher characteristics*

1. *Not in science subsample*—Random half-sample indicator; 1 = Not in the science half-sample, 0 = In the science half-sample.
2. *Female teacher*—Gender of teacher; 1 = Female teacher, 0 = Male teacher (recoded from science teacher data, F1T3_1). Note: This variable is only defined for students in the science half-sample.
3. *Years of teaching*—Total years of teacher at the secondary level (recoded from science teacher data, F1T3_4B). Note: This variable is only defined for students in the science half-sample.
4. *Tcheduc*—Teacher-reported preparation for teaching science (composite includes teacher assessment of adequacy of preparation to teach science [F1T2_14], teaching certificate in science [F1T3_8B], bachelor's degree with science major [F1T310E1], graduate degree with science major [F1T311E11]), z score ($M = 0$, $SD = 1$, alpha-reliability = .160). Note: This variable is only defined for students in the science half-sample.

F. *Measures describing science teachers' reports on class track/grading policies*

1. *Advanced*—Teacher-reported track of science course, 1 = "Advanced Honors," 0 = "Other" (recoded from F1T2_3), fixed reference group: "Academic." Note: This variable is only defined for students in the science half-sample.
2. *General*—Teacher-reported track of science course, 1 = "General," 0 = "Other" (recoded from F1T2_3), fixed reference group: "Academic." Note: This variable is only defined for students in the science half-sample.
3. *Vocat/Other*—Teacher-reported track of science course, 1 = "Vocational" or "Other," 0 = "Other" (recoded from F1T2_3), fixed reference group: "Academic." Note: This variable is only defined for students in the science half-sample.
4. *Gradbehav*—Teacher report of the importance of nonachievement-related behavior in determining student grades (composite includes importance of individual improvement [F1T3_24C], effort [F1T3_24D] class participation [F1T3_24E], completing homework [F1T3_24F], consistent attendance [F1T3_24G]), z score ($M = 0$, $SD = 1$, alpha-reliability = .789). Note: This variable is only defined for students in the science half-sample.
5. *Gradachv*—Teacher-report of the importance of achievement-related behavior (absolute vs. relative) in determining student grades (composite includes importance of absolute achievement [F1T3_24A], and relative achievement [F1T3_24B, reverse-coded]), z score ($M = 0$, $SD = 1$, alpha-reliability = .081). Note: This variable is only defined for students in the science half-sample.

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G. Measures describing science teachers' reports on class activities

1. *Noninstr*—Teacher-reported percent of class time spent on noninstructional activities (composite includes percent time on maintaining order/disciplining students [F1T2_16D] and percent time on routine administrative tasks, taking attendance, making announcements, and so forth [F1T2_16F]), z score ($M = 0$, $SD = 1$, alpha-reliability = .465). Note: This variable is only defined for students in the science half-sample.

2. *Labtime*—Teacher-reported minutes per week class meets for lab [F1T2_15B], z score ($M = 0$, $SD = 1$). Note: This variable is only defined for students in the science half-sample.

3. *Stulab*—Teacher-reported frequency of student lab activity (composite includes how often students do experiments [F1T2S20C], and how often students turn in written report on experiments [F1T2S20E]), z score ($M = 0$, $SD = 1$, alpha-reliability = .719). Note: This variable is only defined for students in the science half-sample.

4. *Labequip*—Teacher-reported quantity and condition of available lab equipment (composite includes amount of available lab equipment [F1T2S25], and condition of available equipment [F1T2S26]), z score ($M = 0$, $SD = 1$, alpha-reliability = .245). Note: This variable is only defined for students in the science half-sample.

Notes

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¹The reliabilities of both tests at Grade 10 have risen from their corresponding values at the 8th-grade level. This occurred despite the fact that the 10th-grade life science test contained one fewer item than the 8th-grade life science test. Although there is some overlap in items between Grade 8 and Grade 10, new items were introduced at the first follow-up, replacing simpler items, to be responsive to curriculum. Simple comparisons between the tests at Grades 8 and 10 are not recommended; the tests are of different length and contain distinct items. We chose not to compare performance on individual items that were identical on both tests, although this is possible. For a full discussion of the psychometric properties of the NELS tests, see Rock and Pollack (1995).

²At alternative stages in the hierarchical OLS analyses, we used a forward-stepwise algorithm for testing interactions. This procedure systematically estimates the extent to which first-order coefficients differ for boys and girls. Although we recognize the atheoretical nature of any stepwise procedure in a conceptual model, it seems useful in this case because we limited such tests to gender interactions. An alternative modeling technique would be to estimate simultaneously and report all second-order effects involving gender (significant or not). Although such an approach does not lead to biased regression estimates, the inclusion of a large number of nonsignificant interaction terms lowers the efficiency of model estimates. In other words, the standard errors of all estimates of interaction effects would be inflated, increasing the difficulty of detecting significant effects. We followed the advice of Aiken and West (1991). In the interest of model parsimony, we retained only significant interaction effects in the final models.

³Rosenthal and Rosnow (1984) provided a useful standard for interpreting effect sizes (from categorical predictors) as measured SD units, which we followed. Effects of .5 SD or more are considered large, effects between .3 and .5 are moderate, and effects between .1 and .3 are seen as small. Effects less than .1 are considered trivial by this standard.

⁴Descriptive summaries of the individual student-reported lab item suggest that lab

activities are not common in most 10th-grade science courses. How often do students use books to show how an experiment works: 44.8% very rarely or once a month, 33.0% once a week, 22.2% almost every day/every day. How often does the teacher demonstrate an experiment: 49.3% very rarely, or once a month; 31.5% once a week; 19.2% almost every day, or every day. How often do students write reports of laboratory work: 55.0% very rarely or once a month, 32.8% once a week, 12.2% almost every day or every day. How often do students conduct their own experiments: 91.0% very rarely or once a month, 6.3% once a week, 2.7% almost every day or every day. It is clear that hand-ons lab experiences are infrequent for all students. Students more often simulate a lab by reading the text, or watching the teacher.

⁵The preparation of U. S. high school science teachers, based on the separate components of our composite, is solid. For example, 94% of these teachers are certified in science; 69% possess a BA or BS degree in science; and 31% possess an MA or MS degree in science. More specifically, 41.3% of the teachers possess only a bachelor's degree in science, 27.5% possess both a bachelor's and a master's, but 27.9% hold neither a graduate nor an undergraduate degree in science (presumably their degrees are in education); 3.3% hold only a master's degree in science.

⁶There is discrepancy between the student-reported and teacher-reported lab experiences. Teachers reported substantially more frequent lab experiences than the students. How often experiments are done by students: 34.8% very rarely or 1-2 times a month, 44.9% once a week, 20.3% 2-3 times per week or every day. How often students write reports on experiments: 47.1% very rarely or 1-2 times a month, 38.5% once a week, 14.4% 2-3 times per week or every day.

⁷We were surprised that neither computer use nor active procedures in high school science classrooms were positively associated with science learning. We concluded that these results were not an artifact of controlling for the other class activities, because we observed the same negative associations as bivariate correlations. Exploratory investigation revealed that these practices, currently favored among many reform advocates, actually occur somewhat more often in science classes identified as enrolling lower ability students. In a separate study, we are pursuing these findings about the effects of instructional practices in science classrooms on students' learning in greater detail.

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