Effects of Inquiry-Based Teacher Practices on Science Excellence and Equity

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ABSTRACT **Within science education reforms, a pedagogical shift from a teacher-centered, textbook-based instructional paradigm to a student-centered, inquiry-based model is called for. Despite strong theoretical grounding, there is limited empirical evidence that these reforms will achieve national goals of academic excellence and equity. The author used hierarchical linear models to estimate the extent to which 5 inquiry-based teacher practices promote achievement of all students (excellence) and reduce gaps in achievement among students with different demographic profiles (equity). Findings suggest that teacher practices that improve overall academic excellence simultaneously are as likely to contribute to greater inequities among more and less advantaged students as they are to close persistent achievement gaps.**

Key words: hierarchical linear models, inquiry-based teacher practices, science excellence and equity

Theoretical Framework

The National Science Education Standards (National Research Council, 1996) include specific guidelines that describe how science instruction should be conducted in high schools. The standards encourage teachers to replace traditional teacher-centered instructional practices, such as emphasis on textbooks, lectures, and scientific facts, with inquiry-oriented approaches that (a) engage student interest in science, (b) provide opportunities for students to use appropriate laboratory techniques to collect evidence, (c) require students to solve problems using logic and evidence, (d) encourage students to conduct further study to develop more elaborate explanations, and (e) emphasize the importance of writing scientific explanations on the basis of evidence.

There is substantial empirical and theoretical evidence that inquiry-based instruction is a starting point for personal construction of meaning and can lead to higher achievement of all students (Anderson, 1997; Burkam, Lee, & Smerdon, 1997; Carey, 1985; Carmichael et al., 1990; Ertepinar & Geben, 1996; Freedman, 1997; Glasson, 1989; Lee & Burkam, 1996; Lee, Chen, & Smerdon, 1996; Odubunmi & Belogun, 1991; Piaget, 1970; Stohr-Hunt, 1996; von Glaserfeld, 1984, 1987; Von Secker & Lissitz, 1999). One question that has not been well explored is whether the "payoff" associated with specific instructional practices varies significantly for individuals with different probabilities of academic success.

Most of the variability in science achievement has been attributed traditionally to socioeconomic status (SES), minority status, and gender (Coleman et al., 1966; Gibbons, 1992; Hilton & Lee, 1988; Hoffer, Rasinski, & Moore, 1995; Madigan, 1997; Mason & Kahle, 1989). In general, evidence explaining how teacher practices interact with combinations of student background variables or social context to influence science achievement is sparse. One of the criticisms of the standards is that, although they emphasize the importance of science achievement for all students regardless of demographic status, proposed science education reforms do not directly address theoretical issues surrounding ethnic, socioeconomic, and gender equity (Rodriguez, 1997). Although evidence exists that differences in teacher practices explain some discrepancies in achievement (McCauley, 1995; National Center for Education Statistics, 1992), there is no empirical evidence to support the viability and utility of proposed instructional reforms for creating more equitable opportunities for students nationwide (Donmoyer, 1995; Riechard, 1994).

In this analysis, I extend the focus of the policy discussion beyond a description of background variables associated with the statistical risk of low science achievement and study of the interaction of gender, SES, and race–ethnicity as social contexts, or collections of variables that alter the psychological significance and social demands of life events and the subsequent relationship with academic risk. Understanding whether, and to what extent, inquiry-based teacher practices influence science achievement in social contexts will provide clues about how to foster more equitable educational opportunities for all students.

In this evaluation, I sought to answer the following general questions:

1. How much can inquiry-based instruction influence academic excellence of all students, regardless of social context?

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2. Do teacher practices interact with student background variables to produce more equitable science achievement in some social contexts than in others?

Method

Data Sources

Data for this analysis were obtained from the first follow-up (10th grade) of the National Education Longitudinal Study (NELS) sponsored by the National Center for Education Statistics, U.S. Department of Education. NELS focuses on the personal and academic experiences of students as they progress from 8th grade to high school and beyond. The NELS first follow-up survey in 1990 comprised a national probability sample of all regular public and private 10th-grade schools in the 50 states and the District of Columbia in the 1989–1990 academic year. In the evaluation, I used a sample of approximately 4,377 students in 1,406 classes who fit the following filters: (a) demographic data available, (b) enrolled in 10th grade during the 1989–1990 academic year, (c) 10th-grade science achievement data available, and (d) biology teacher questionnaire available. Students from various cells defined by the classification scheme were sampled with different probabilities of inclusion. Therefore, we weighted data to adjust the contribution of each case according to the number of other individuals in the sampled population whom he or she represented and to account for sampling error due to random discrepancies within the population.

Instrumentation

Three demographic characteristics are available in the first follow-up data file, namely, gender, race–ethnicity, and SES. In this study, boys were assigned values of 1 and girls were assigned values of 0. We reclassified students' racial–ethnic status as either minority or majority to maintain sufficient subgroup size. Therefore, African American, Hispanic, and American Indian students were assigned values of 1 (minority); Caucasian American and Asian American students were assigned values of 0 (majority). This approach was justified because of the similarities in the distribution of science achievement among groups of students who were assigned each value. SES is a standardized composite variable developed by the National Center for Education Statistics, using base-year, parent-questionnaire data, such as family income and the education level and occupation of each parent. The SES quartile variable used in this analysis indicates the quartile into which the value for a student's SES falls. Each of 16 unique social contexts was defined as the combination of three demographic characteristics, namely, gender (male or female), minority status (majority or minority), and SES quartile (Quartile 1 is the lowest SES). An itemization of the number of students with each demographic profile (social context) is shown in Table 1.

I measured science achievement with a standardized science test developed by the Educational Testing Service expressly to measure higher order thinking as well as understanding of fundamental concepts and mastery of basic skills. Observed science achievement scores for students in this sample are shown in Figure 1.

Measurements of teacher practices were selected from items on the NELS teacher questionnaire that asked teachers to report how much emphasis they place on (a) eliciting student interest and engagement, (b) using appropriate laboratory techniques, (c) problem solving, (d) conducting further study, and (e) scientific writing. This analysis estimated the individual and combined effects of these five teacher practices on the science achievement of individuals with different probabilities of academic risk.

A limitation of this study is that teachers were not sampled randomly, and generalizations about teacher characteristics are unwarranted. The results of this analysis apply to a subsample of students who were in Grade 10 in 1990. The results are intended to be suggestive, not conclusive. They can be used to inform discussions about the effect of teacher practices on achievement and equity, but they should not be used to prescribe policy.

Analytic Model

In this analysis, I used two-level hierarchical linear models (HLMs) to examine individual and unique associations of teacher practices with the science achievement of 4,377 high school students (Level 1) in 1,406 biology classrooms (Level 2). HLM calculates both intercept and slope heterogeneity. Therefore, estimates of associations of teacher practices with science achievement included analysis of the direct effect of teacher practices on average achievement of students in different classes and analysis of indirect effects (cross-level interactions) of teacher practices on the achievement of individuals in the same class. A detailed explanation of the data analysis methods used by HLM is available in Bryk and Raudenbush (1992).

Preliminary analysis. The simplest HLM equation for estimating achievement, Y_{ij}, of person i in class j is: $Y_{ij} = \beta_{0j} + r_{ij}$. In this preliminary model, β_{0j} represents the mean achievement of class j, and r_{ij} is the deviation of the achievement of person i from mean achievement of class j. R_{ij} is assumed to be normally distributed with mean 0 and variance σ^2. The Level 2 equation for the random intercept, β_{0j}, has the form $\beta_{0j} = \gamma_{00} + \mu_{0j}$. Here, γ_{00} equals the grand-mean achievement for the population of classes, and μ_{0j} is the deviation of the mean of class j from grand-mean achievement. The values of μ_{0j} are assumed to be normally distributed with mean 0 and variance $\grave{U}_{00}$. The expanded equation is: $Y_{ij} = \gamma_{00} + \mu_{0j} + r_{ij}$.

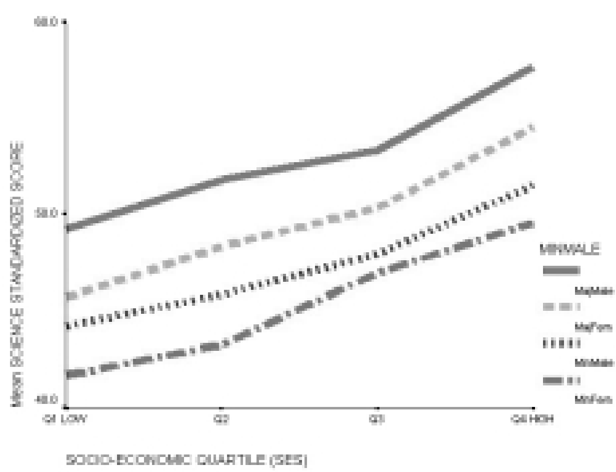
Preliminary HLM analysis partitioned variance in science achievement into that part that was unique to classes ($\grave{U}_{00}$) and the pooled within-class residual ($\hat{U}^2$). I used these estimates of the variance components to calculate the *intra-*

Table 1.—HLM Level 1 Estimates of Effects of Social Context on Science Achievement

Race/ethnicity and gender	SES quartile	*n*	Weighted %	Predicted science achievement[a]	Effect of class mean[b]	Effect of social context[c]
Minority female	1 (low)	227	5.23	36.77	–1.05	–0.87
Minority female	2	134	2.98	41.31	–0.66	–0.57
Minority female	3	96	2.02	47.24	–0.04	–0.28
Minority female	4	72	1.45	51.44	0.30	0.01
Minority male	1	199	4.37	41.31	–0.79	–0.48
Minority male	2	135	3.00	43.86	–0.65	–0.26
Minority male	3	80	1.65	47.83	–0.26	–0.04
Minority male	4	50	1.00	52.45	0.25	0.18
Majority female	1	272	6.56	45.18	–0.29	–0.36
Majority female	2	453	10.38	49.50	0.05	–0.06
Majority female	3	466	10.92	53.32	0.31	0.24
Majority female	4	563	11.44	57.37	0.61	0.54
Majority male	1	203	5.13	51.38	–0.22	0.39
Majority male	2	391	9.67	55.50	0.14	0.65
Majority male	3	466	11.19	56.11	0.30	0.61
Majority male	4	570	13.00	61.68	0.91	0.87

Note. Cases are weighted by normalized F1QWT to adjust the contribution of each case according to the number of other individuals in the sampled population whom he or she represented. N = 4,377. HLM = hierarchical linear modeling.
[a]Predicted achievement of individual i in class j was calculated by using the Level 1 equation, $Y_{ij} = \beta_{0j} + \Sigma\beta_{pj}(X_p)$. Thus, predicted achievement for each social context was the sum of the average class achievement for individuals with that demographic profile, plus the sum of the products of the slope coefficients times the grand-mean centered value used in the Level 1 model. [b]The effect size was the standard deviation difference in science achievement for classes that included students with this profile. [c]The effect size was the estimated standard deviation difference in science achievement associated with each demographic profile over and above that explained by differences in class means.

Figure 1. Effects of Social Context on Science Achievement



class correlation, an index that measures the degree to which students who attend the same class are more like each other than they are like students in other classes. The intraclass correlation (Ú) is shown by the following formula: $Ú = Ù_{00}/(Ù_{00} + Û^2)$. Using HLM to control for cluster effects is justified even when intraclass correlations are as low as .02 (Kreft & De Leeuw, 1998). The adjusted intraclass correlation for between-classes variability in this sample was .52. Ignoring this very high intraclass correlation and analyzing disaggregated data using traditional multiple regression techniques rather than HLM could have led to underestimation of the effects of instruction on science achievement.

Within-class model. In the within-class, or Level 1 model, the j regression equations (one per class) predicting individual achievement included a random intercept and seven nonrandomly varying predictors of demographic status ($_p$), namely, SES, gender, racial–ethnic status, and their two-way and three-way interactions. I used SES to measure differences in achievement associated with family advantage. I included two dichotomous measures (i.e., male and minority) to control for gaps in achievement that could be explained by gender or minority status, respectively. The within-class regression equations varied as a function of mean class achievement and the relative strength of the effects of p student demographic characteristics. The equation for predicting an outcome for individual i in class j was: $Y_{ij} = \beta_{0j} + \beta_{pj}(X_p) + r_{ij}$. All student-level characteristics (X_p) were grand-mean centered. Because random variance components were not estimated for nonrandomly varying predictors (β_{pj}), the pth slope coefficient in every class j was equal to the grand mean of the respective slope coefficient, (γ_{p0}), for all classes. The within-class equation can be interpreted as follows:

β_{0j} = mean outcome of all students in class j,
β_{1j} = difference in achievement in class j associated with 1 standard deviation change in SES,
β_{2j} = gender gap in achievement in class j,

β_{3j} = minority gap in achievement in class *j*,
β_{4j} = two-way interaction of SES and gender with achievement in class *j*,
β_{5j} = two-way interaction of SES and minority status with achievement in class *j*,
β_{6j} = two-way interaction of gender and minority status with achievement in class *j*,
β_{7j} = three-way interaction of SES, gender, and minority status with achievement in class *j*,
r_{ij} = deviation of person *i* from mean achievement of class *j* when demographic status is controlled

Between-classes model. The direct effects of teacher practices (W_q) on the mean class achievement and on the cross-level interactions of classroom instruction with student-level characteristics were estimated in the between-classes (Level 2) model. I used six HLMs to evaluate the individual and combined effects of five teacher practices on science achievement. The following are Level 2 equations for estimating the individual effect of teacher practice *q*:

$$\beta_{0j} = \gamma_{00} + \gamma_{0q}(W_q) + \mu_{0j}, \quad \beta_{pj} = \gamma_{p0} + \gamma_{pq}(W_q).$$

The following are the Level 2 equations for estimating the combined effects of five teacher practices:

$$\beta_{0j} = \gamma_{00} + \gamma_{0q}(W_q) + \mu_{0j}, \quad \beta_{pj} = \gamma_{p0} + \gamma_{pq}(W_q).$$

Because measures of teacher practices were grand-mean centered, the Level 2 equations can be interpreted as follows:

γ_{00} = grand mean science achievement for classes where teacher emphasis on one (or five) teacher practice(s) *q* is average,
γ_{0q} = deviation in achievement associated with 1 standard deviation change in a teacher practice *q*,
μ_{0j} = deviation of class *j* from γ_{00} when teacher emphasis on practice *q* is average,
γ_{p0} = average effect of the *p*th demographic characteristic or interaction on individual achievement,
γ_{pq} = deviation from γ_{p0} associated with a one-unit change in teacher practice *q*.

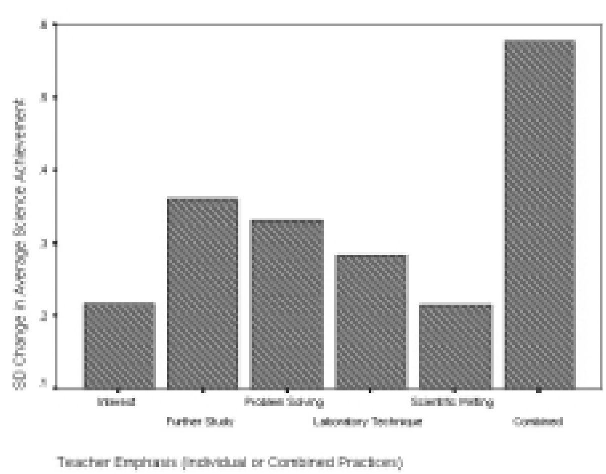
The expanded equation for the between-classes model was $Y_{ij} = (\gamma_{00} + \gamma_{0q}W_{qj} + \mu_{0j}) + (\gamma_{p0} + \gamma_{pq}W_{qj})(X_{ij}) + r_{ij}$. I applied this model to predict the direct and indirect effects on science achievement of greater teacher emphasis on inquiry-based instructional practices for students with various demographic profiles.

Predicting Changes in Science Achievement

Calculating direct effects of instructional practice on class means. Predicted mean achievement of a student in class *j* when teacher emphasis on all practices was average was calculated using the Level 1 equation $\beta_{0j} = \gamma_{00} + \mu_{0j}$. The Level 2 equations predicting changes in class mean achievement associated with the individual effect of one teacher practice *q* and the combined effects of using five teacher practices *q* were $\beta_{0j} = \gamma_{00} + \gamma_{0q}(W_q) + \mu_{0j}$ and $\beta_{0j} = \gamma_{00} + \gamma_{0q}(W_q) + \mu_{0j}$, respectively. I calculated conservative estimates of the sizes of the effects of an increase of 1 standard deviation in teacher emphasis on either one individual practice or on the combination of five practices on class means by dividing the difference in the predicted values of β_{0j} obtained from the Level 1 and Level 2 equations by the standard deviation of the intercept obtained from the pooled within-class HLM, a value that is assumed to be the same for all classes. Results of this analysis are shown in Figure 2.

Calculating interactions of instructional practice with social context. Social context was defined as the combined effect of three demographic characteristics (i.e., SES quartile, minority status, and gender) and their two-way and three-way interactions; I calculated it by summing the products of the slope coefficients with their respective grand-mean centered predictors, $\beta_{pj}(X_p)$. I calculated the predicted effect of social context on achievement of individual *i* in class *j* when teacher emphasis on a strategy was average (see Table 1, last column) using estimates of slope coefficients obtained from the Level 1 model, namely, $\beta_{pj} = \gamma_{p0}$. The Level 2 equations predicting changes in each slope coefficient, *p*, associated with the individual effect of teacher practice, *q* or the combined effects of using five teacher practices, *q* were $\beta_{pj} = \gamma_{p0} + \gamma_{pq}(W_q) + \mu_{0j}$ or $\beta_{pj} = \gamma_{p0} + \gamma_{pq}(W_q) + \mu_{0j}$, respectively. I calculated the size of the effect of an increase of 1 standard deviation increase in teacher emphasis on either one individual practice or the combination of five practices on class means by dividing the difference in the predicted values of $\beta_{pj}(X_p)$ obtained from the Level 1 and Level 2 equations by the pooled within-group standard deviation obtained from the within-class HLM, a value assumed to be the same for all classes. Results of this analysis are shown in Figures 3–7.

Figure 2. Effects of Teacher Practices on Average Achievement



Results

Effects of Social Context on Achievement: The Within-Class HLM

I used the within-class (Level 1) model to estimate individual science achievement as a linear function of the mean achievement of students in class *j*, gender, minority status, and SES. The result of the within-class HLM, the details of which are provided in Table 2, show that a significant amount of the variability in student achievement was explained by demographic status. Regardless of the average achievement of the class, 10th-grade science achievement was 0.48 standard deviations lower for girls than for boys and 0.51 standard deviations lower for minority students than for majority students. Predicted science achievement was 0.30 standard deviations higher for every quartile increase in SES.

Figure 3. Effects of Social Context on Academic Equity

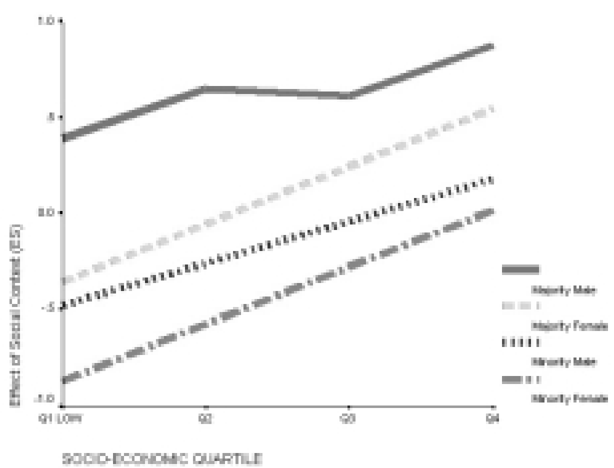


Figure 4. Effects of Greater Emphasis on Interest in Academic Equity

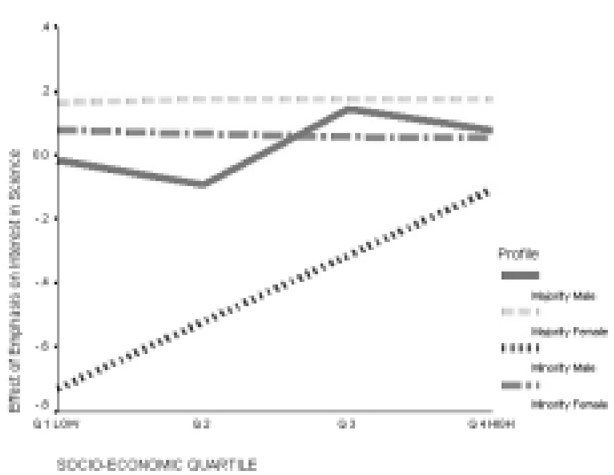


Figure 5. Effects of Emphasis on Further Study on Academic Equity

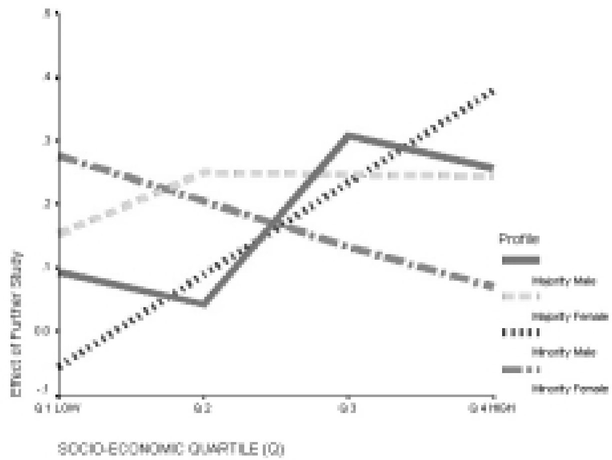


Figure 6. Effects of Laboratory Emphasis on Academic Equity

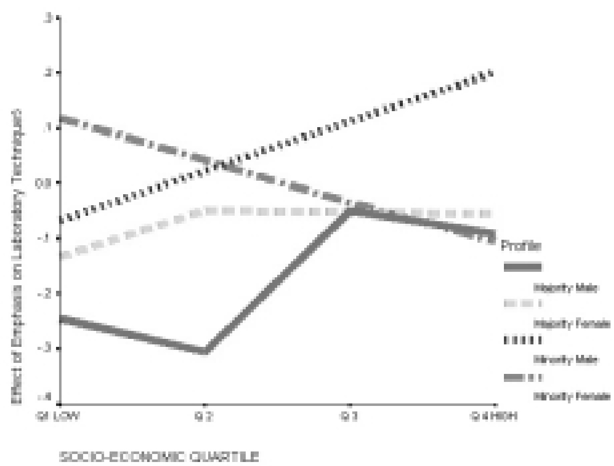


Figure 7. Effects of Problem-Solving Emphasis on Academic Equity

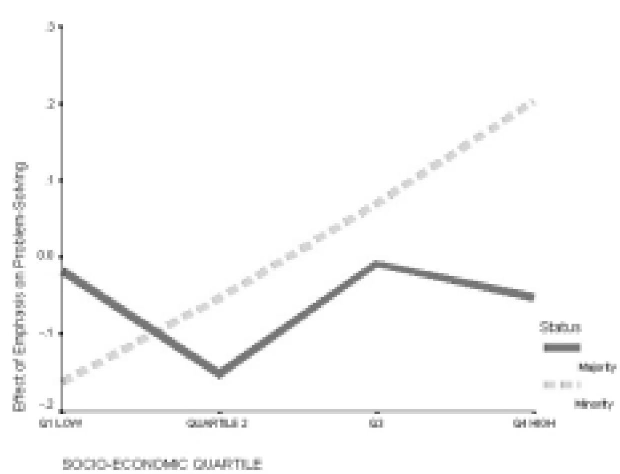


Table 2.—Results of Within-Class HLM Analysis of Effects of Demographic Status on Science Achievement

Fixed effect	β coefficient	*SE*	*t* ratio	*df*	*p*	*ES*[a]
Class achievement	49.850	0.187	267.004	1,405	.000	
Male	3.765	0.927	4.060	4,369	.000	0.484
Minority	–3.992	0.901	–4.430	4,369	.000	–0.513
Socioeconomic status	2.335	0.197	11.881	4,369	.000	0.300
Minority × Male	–0.063	1.567	–0.040	4,369	.968	–0.008
Minority × SES	–0.019	0.427	–0.045	4,369	.964	–0.002
Male × SES	–0.305	0.319	–0.958	4,369	.339	–0.039
Minority × Male × SES	–0.316	0.717	–0.441	4,369	.659	–0.041

Random effects[b]	*SD*	Variance	*df*	Chi-square	*p*
τ U0	4.667	21.777	1,405	3,119.5437	.000
σ^2_R	7.409	54.900			

Note. Deviance = 4,100.19479; Deviance change from fully unconditional model = 77.96.
[a]The effect size for a slope coefficient describing students' characteristics was equal to the value of the beta (β) estimated by the unconditional model (shown above),divided by the pooled within-groups standard deviation estimated by a model with no predictors (*SD* = 7.776; model is not shown). The formula was *ES* = β/7.776. [b]Preliminary hierarchical linear model analysis indicated that random effects were not significant for slopes describing the effects of student characteristics on achievement. The HLM was respecified as a random-intercept model, and slope coefficients were allowed to vary nonrandomly.

Examination of the random parts of the HLM (Table 2) showed that even when differences in science achievement that could be explained by class means and social context were controlled, there was still significant variability in achievement that could be explained by differences in the instructional practices of teachers who taught those classes.

Effects of Teacher Practices in Social Contexts: The Between-Classes HLM

I used HLM to estimate the impact of teacher practices in terms of value-added effects. Value-added indices assess effects after controlling for demographic status. Without the adjustment of class means to account for some students being more or less advantaged than others, classes with higher concentrations of majority students of above-average SES would have been more likely to have higher average achievement scores regardless of how they were taught. Using a value-added approach "leveled the playing field" and allowed meaningful between-classes comparisons.

Detailed results of the between-classes HLM analyses are shown in Tables 3 and 4. The effect sizes are standard deviation differences that represent the change in an intercept or slope coefficient associated with a 1 standard deviation increase in teacher emphasis on a given practice. The effects associated with the intercept represent differences in mean achievement of a class associated with 1 standard deviation more emphasis on a teacher practice. These differences suggest how teacher practices can affect overall achievement or excellence. Effects associated with slope coefficients represent indirect influences or cross-level interactions of teacher practices with demographic status. These effects represent changes in the size and direction of slope coefficients that occur in classes where the amount of emphasis on a teacher practice is 1 standard deviation above average. Changes in slope coefficients suggest how teacher practices might contribute to more equitable achievement among students with different demographic profiles.

The trivial effect sizes of slope coefficients shown in Tables 3 and 4 suggest that teacher practices have little chance of influencing academic equity. However, further analysis of these results suggested that the combined teacher practices interact with social context in ways that are not obvious from preliminary examination of this output.

Predicting Achievement Change

I used estimates of the intercept and slope coefficients obtained from the within-class HLM to predict achievement of individuals with distinct demographic profiles when teacher emphasis on all instructional practices was average. As shown in Table 1, predicted differences in science achievement were more striking when demographic status variables were viewed as contributing collectively to social contexts that influence learning. As predicted from the intraclass correlation, students were more likely to be enrolled in classes with students like themselves. For example, classes that included minority girls had lower achievement, on average, than did classes without that population, regardless of SES. Further, social context had an effect on achievement over and above that explained by mean class differences. For example, science achievement of minority girls from disadvantaged families (SES Quartile 1) was 0.88 standard deviations lower than that for minority girls from families in the highest SES quartile.

Table 3.—Individual Direct and Indirect Effects of Five Teacher Practices on Science Achievement

Fixed effect	Interest in science	Further study	Problem solving	Laboratory techniques	Scientific writing
Class achievement (γ01)[a]	0.22	0.36	0.33	0.28	0.22
Male (γ11)[b]	0.04	0.04	0.03	0.03	0.01
Minority (γ21)	–0.01	0.03	–0.05	0.05	–0.02
Socioeconomic status (γ31)	0.01	0.00	–0.04	0.01	–0.03
Minority × Male (γ41)	–0.09	–0.10	–0.02	–0.06	0.00
Minority × SES (γ51)	–0.01	–0.04	0.08	–0.03	0.02
Male × SES (γ61)	–0.05	–0.02	–0.01	–0.03	0.00
Minority × Male × SES (γ71)	0.09	0.08	–0.02	0.06	0.00
Random effect	*SD*	*SD*	*SD*	*SD*	*SD*
τU0	4.636	4.568	4.550	4.590	4.630
σ	7.409	7.391	7.405	7.399	7.407

[a]The effect size of a γ coefficient predicting a random intercept was computed by dividing the gamma coefficient by the standard deviation of the intercept obtained from the within-class model. [b]The effect size of a γ coefficient describing the cross-level interaction of a teacher practice with demographic status was calculated by dividing the value of the gamma (γ) estimated by the between-classes model by the standard deviation of the slope coefficient (β). The standard deviation of a nonrandomly varying β was equal to the standard error estimated by the within-class model times the square root of the sample size. The formula used in this model was $ES = \gamma/[SE\beta * \text{sqrt}(1{,}406)]$.

Table 4.—Combined Direct and Indirect Effects of Five Teacher Practices on Science Achievement

Variable	*ES*	Variable	*ES*
Class achievement (γ00)		Minority × Male (γ40)	
γ01 Interest	0.01	γ41 Interest	–0.06
γ02 Further study	0.24	γ42 Further study	–0.08
γ03 Problem solving	0.20	γ43 Problem solving	0.04
γ04 Laboratory techniques	0.11	γ44 Laboratory techniques	–0.06
γ05 Scientific writing	0.02	γ45 Scientific writing	0.05
Male		Minority × Socioeconomic Status (γ50)	
γ11 Interest	0.03	γ51 Interest	–0.03
γ12 Further study	0.02	γ52 Further study	–0.05
γ13 Problem solving	0.02	γ53 Problem solving	0.13
γ14 Laboratory techniques	0.02	γ54 Laboratory techniques	–0.07
γ15 Scientific writing	–0.03	γ55 Scientific writing	0.02
Minority (γ20)		Male × SES (γ60)	
γ21 Interest	0.01	γ61 Interest	–0.05
γ22 Further study	0.03	γ62 Further study	–0.01
γ23 Problem solving	–0.09	γ63 Problem solving	0.01
γ24 Laboratory techniques	0.10	γ64 Laboratory techniques	–0.04
γ25 Scientific writing	–0.03	γ65 Scientific writing	0.02
SES (γ30)		Minority × Male × SES (γ70)	
γ31 Interest	0.04	γ71 Interest	0.08
γ32 Further study	0.00	γ72 Further study	0.06
γ33 Problem solving	–0.06	γ73 Problem solving	–0.09
γ34 Laboratory techniques	0.03	γ74 Laboratory techniques	0.08
γ35 Scientific writing	–0.02	γ75 Scientific writing	–0.03

Random effect	*SD*	Variance	χ^2	*df*	*p*
τU0	4.498	20.233	2,954.1404	1,400	.000
s^2_R	7.392	54.647			

[a]The effect size of a gamma coefficient predicting a random intercept was computed by dividing the gamma coefficient by the standard deviation of the intercept obtained from the within-class model. [b]The effect size of a gamma coefficient describing the cross-level interaction of a teacher practice with demographic status was calculated by dividing the value of the gamma (γ) estimated by the between-classes model by the standard deviation of the slope coefficient (β). The standard deviation of a nonrandomly varying β was equal to the standard error estimated by the within-class model times the square root of the sample size. The formula used in this model was $ES = \gamma/[SE\beta * \text{sqrt}(1{,}406)]$.

Direct associations of teacher practices with average achievement. The identified teacher practices were associated with higher science achievement of all students (Figure 2). On average, science achievement of a class increased by 0.58 standard deviations for every 1 standard deviation increase in the amount of emphasis that their teachers placed on an inquiry approach that combined the following five practices, namely, (a) eliciting student interest and engagement, (b) using appropriate laboratory techniques, (c) problem solving, (d) conducting further study, and (e) scientific writing. The influences of inquiry-based teaching practices also were significant when each practice was considered individually. When student demographic status was controlled, the expected improvement in average achievement associated with a 1 standard deviation increase in emphasis on student interest and engagement was 0.22 standard deviations; on appropriate laboratory techniques, 0.28 standard deviations; on problem solving, 0.33 standard deviations; on further study, 0.36 standard deviations; and on scientific writing, 0.22 standard deviations. This finding provides empirical support for reforms recommended by the National Science Education Standards. Inquiry-based instructional practices are associated with academic excellence, regardless of social context.

Interactions of teacher practices with demographic status. Although the finding that the teacher practices described in the previous paragraphs were associated with higher achievement of all students was encouraging, it does not support arguments claiming that differences in the way students are taught will result in more equitable achievement among the more and less advantaged students. Examination of the interactions of individual teacher practices with demographic status revealed differences suggesting that teacher practices have greater influence in some social contexts than in others, even among students in the same class.

The results described in the following paragraphs represent the indirect effects of teacher practices on science achievement. That is, they describe the changes in the slope coefficients that predict the direct effects of demographic status on the science achievement of students within each class (Figure 3) when teacher emphasis on a particular instructional practice is 1 standard deviation more than average. Positive effects indicate that students with a given demographic profile have higher achievement than do comparable students in classes where teacher emphasis on the relevant instructional practice is average.

Interpretation of the influence of teacher practices on academic equity is more complicated than interpretation of the effects of teacher practices on excellence because the implications depend on risk status. Among students whose achievement is traditionally high, positive effects can exacerbate academic gaps, particularly if the effects are less beneficial for students at risk. Likewise, among students already at risk, negative effects suggest that the influence of teacher practices will be associated with even lower achievement.

Emphasis on interest. The HLM analysis suggested that teacher emphasis on interest in science influenced the three-way interaction of SES, gender, and minority status on science achievement (Figure 4). Compared with their female counterparts in classes where teacher emphasis on student interest was average, predicted science achievement was 0.17 standard deviations higher for majority girls and 0.07 standard deviations higher for minority girls, regardless of SES. This finding suggests that although emphasis on interest in science can reduce some risks associated with gender, it could increase gaps in achievement of majority and minority girls. The effects of teacher practices on social context were small for majority boys (0.04 standard deviations). Emphasizing interest in science was associated with less equitable achievement for minority boys, particularly those from poor families. Compared with other minority boys from families of the same SES, achievement of low-SES and high-SES minority boys was –0.73 standard deviations to –0.11 standard deviations lower, respectively, in classes where teachers emphasized student interest.

Emphasis on further study. The HLM analysis revealed that emphasis on further study had a significant effect on the two-way interaction of minority status and gender with achievement. The effects of teacher emphasis on further study were the same in most social contexts defined by combinations of minority status and gender (approximately 0.21 standard deviations). Benefits associated with emphasizing further study were smaller for minority boys (0.08 standard deviations) than for other groups. This finding demonstrates the complicated nature of the interaction of teacher practices with social context. Emphasizing further study was associated simultaneously with higher achievement for all girls but with an increase in the gap in achievement between majority and minority boys.

Teacher emphasis on further study significantly influenced the effect of the three-way interaction of SES, minority status, and gender with science achievement. This interaction would have been overlooked in a model that examined only main effects or two-way interactions, rather than the collective interactive influences of three dimensions of social context (Figure 5). Among students from the most advantaged families (SES Quartile 4), risks associated with demographic status were 0.38 standard deviations lower for minority boys and 0.07 standard deviations lower for minority girls in classes where teachers emphasized further study, compared with their counterparts in classes where emphasis on further study was average. The effects for high-SES minority students were offset by gains of about 0.25 standard deviations for high-SES boys and girls. Although all high-SES students benefited from this instructional practice, the net effect for high-SES minority girls was an increase in the achievement gap.

Among the poorest students (SES Quartile 1), the pattern of influence observed for high-SES students was reversed. In classes where teachers placed greater emphasis on further study, risks associated with demographic status were

0.28 standard deviations lower for minority girls, but slightly higher (0.05 standard deviations) for minority boys. The benefits for low-SES minority girls were somewhat offset by gains of 0.09 and 0.15 standard deviations, respectively, for low-SES boys and girls. However, emphasizing further study was associated with greater academic inequities among low-SES minority boys and other low-SES students.

Emphasis on laboratory techniques. On average, emphasizing appropriate laboratory techniques was associated with more equitable patterns of achievement in social contexts defined by interactions of minority status and gender. Advantages associated with being majority male or female students were 0.15 standard deviations and 0.07 standard deviations less, respectively. Among minority students, academic risks were reduced slightly (0.02 standard deviations and 0.05 standard deviations, respectively), compared with similar students in classes where emphasis on laboratory techniques was average. These small effects became more suggestive when social context was defined in terms of SES, as well as gender and minority status. Among students of the same SES, there were differences of as much as 0.37 standard deviations in the effects of this practice, depending on the combined influences of gender and minority status.

As shown in Figure 6, there were significant differences in the effect of emphasis on laboratory technique for minority students of different SES. Among low-SES minority students in classes where teacher emphasis on laboratory techniques was 1 standard deviation above average, risks associated with being female were 0 .12 standard deviations less, but risks associated with being male were slightly (0.07 standard deviations) higher. This trend was reversed among high-SES minority students where risks associated with being male were 0.20 standard deviations lower, but risks associated with being female were 0.10 standards deviations higher. Advantages associated with majority status were less pronounced in classes where teacher emphasis on laboratory techniques was 1 standard deviation above average, particularly among low-SES boys.

Emphasis on scientific writing. Although emphasizing scientific writing was associated with higher achievement for all students, I found no indication that this teacher practice would contribute to more equitable science achievement in different social contexts. This finding is important because many of the reforms aimed at raising standardized test scores and narrowing achievement gaps focus on improving students' writing skills. Results suggest that such an expectation is unjustified.

Emphasis on problem solving. As shown in Figure 7, emphasizing problem solving was associated with more equitable achievement among majority and minority students of high SES, but with greater achievement gaps among majority and minority students of low SES. Among high-SES students, advantages associated with being a majority male or female were reduced slightly (0.05 standard deviations), and risks associated with minority status were 0.20 standard deviations less in classes where teacher emphasis on problem solving was 1 standard deviation higher than average. However, among low-SES students, a slight decrease in advantages associated with majority status (0.02 standard deviations) was accompanied by an increase in risks associated with minority status of 0.16 standard deviations.

Discussion

The purpose of this study was to estimate the effects of inquiry-based instructional practices on academic excellence and equity. The associations presented in this cross-sectional analysis are not evidence of causal associations, but they can inform discussion about the effect of teacher practices on achievement and equity. The results provide empirical evidence to support theoretical claims that greater emphasis on inquiry-based teaching is associated with higher science achievement overall. However, the effect of inquiry-based teaching is sensitive to social context differences, and these practices are as likely to exacerbate achievement gaps among some groups of students as they are to narrow them among others.

The instructional choices that teachers make do not affect all students equally. Even within the same classroom, relationships of teacher practices with science achievement may be influenced by the demographic profiles of the students. Evaluation of the relative effects of teacher practices in unique social contexts helps to explain the persistence of academic inequity, even when teachers adopt recommendations prescribed in the National Science Education Standards. The "payoff" of the instructional reforms may vary significantly for individuals with different probabilities of academic success.

The findings in this study have implications for teacher training. There is no evidence that instructional reform is a panacea for the national problem of low achievement, particularly among disadvantaged populations. The associations observed in this study, however, illustrate the importance of increasing teachers' awareness of the need to develop diverse instructional repertoires and the skills to deliver them. Investments in classroom conditions that facilitate multimodal methods of inquiry and accommodate differences in individual learning styles and backgrounds are most likely to pay dividends in terms of academic excellence and equity.

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