Success in Introductory College Physics: The Role of High School Preparation

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ABSTRACT: High school teachers and college physics professors differ in their beliefs concerning the extent to which a high school physics course prepares students for college physics success. In this study of 1,933 introductory college physics students, demographic and schooling factors account for a large fraction of the variation in college physics grades at 18 colleges and universities from around the nation. Controlling for student backgrounds, taking a high school physics course has a modestly positive relationship with the grade earned in introductory college physics. More rigorous preparation, including calculus and 2 years of high school physics, predicts higher grades. Students who had high school courses that spent more time on fewer topics, concepts, problems, and labs performed much better in college than those who raced through more content in a textbook-centered course. College professors should recognize that a substantial fraction of the variation observed in the performance of students they teach can be explained by the range in effectiveness of their pre-college preparation, not simply innate ability. Although students without a high school physics course often do well in college physics, they are more likely to be academically stronger, with more educated parents, having previously taken calculus, and taking physics in their sophomore or junior year in college. *Sci Ed* **85:**111–136, 2001.

INTRODUCTION

Physics marks the final stage of high school science and is taken by the top 25% of students nationally (National Science Foundation, 1993). These students are the nation's future science teachers, doctors, scientists, and engineers, later enrolling in college physics to satisfy program requirements in their chosen field.

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High school teachers make much of preparing their students for success in college courses. Students who plan to pursue college science are encouraged to prepare with high school courses in biology, chemistry, and physics.[1] Yet, college physics professors are less sanguine about the preparation that high school physics provides. Many are dismayed by the difficulty that students have in their introductory courses in spite of their preparation. Dropout and failure rates are high in these "gate-keeping" courses (Gainen, 1995). While success in introductory physics opens the door for students to opportunities in engineering, medicine, and scientific research, failure in these courses closes those career options and presses students toward nonscience fields, negating years of preparation and aspiration.

There is a wide gulf between the views of high school teachers and college professors. Science teachers view their high school physics courses as valuable preparation for introductory college physics, yet many college professors have expressed doubts about their worth (Gibson & Gibson, 1993; Halloun & Hestenes, 1985; Razali & Yager, 1994; Shumba & Glass, 1994). Who is right? Prior research has examined this issue, attempting to measure the impact of high school courses on success in college physics. While some researchers found a positive relationship between high school physics enrollment and doing well in college physics, even identifying the laboratory experience as the key factor, others were dismayed at the puny predictive power of previous preparation (including advanced placement courses) on college physics success.

The authors of this article feel that the relationship between high school and college courses is an important issue to study. More than 800,000 students now take physics in high school each year (Neuschatz & McFarling, 1999), about half of whom go on to take college physics. Many policy changes have been suggested to "strengthen" high school physics. Some have been implemented with little evidence to support their value. A study that explores such variables, including demographic variables introduced as controls, could be a valuable addition to the current debate.

This study quantifies the relationship between high school preparation and introductory college physics success. Through the voluntary involvement of 19 physics professors at 18 colleges and universities nationwide and their 1,933 students, we examined both the amount and the characteristics of high school physics courses in light of student performance in introductory college physics. The ability to control for demographic and school factors in this large student sample helped to isolate the relationship of a variety of approaches, curricula, and methods of teaching.

A major goal of this study is to aid high school physics teachers in reflecting upon the courses that they teach for college-bound students. Preparation for college is certainly not the only reason to take high school physics. Many teachers are interested in promoting scientific literacy, in helping students to think analytically, or in having students understand the impact of science on the world (Hoffer, 1996). Yet many teachers express a strong desire to optimize the future success of their students in college science courses through their decisions of which text to use, what content areas to emphasize, and the mathematical level on which to draw (Hoffer, Quin, & Suter, 1996). Many teachers use nontraditional techniques (no texts, fewer topics, and project work) that they feel are particularly effective and must defend their decisions to skeptical parents and administrators. This study also holds lessons for college professors who want to build upon their students' preparation or emulate the best high school practice in their college courses. In addition, students must decide on which level physics course to take, how far they should go in high school

[1] Indeed, many high school physics teachers we have spoken with report that their students who return tell of the usefulness of their high school preparation. Few return to tell their high school course was not helpful.

mathematics, and how hard they should work in their physics class. This study seeks to identify the possible effects of the decisions that students and their teachers make.

PRIOR RESEARCH

Previous studies carried out at individual colleges tested the association between variables such as high school grades, coursework, or standardized test scores and success in college physics. Gifford and Harpole (1986) found that for 248 Mississippi State University students, high school math grades, taking high school physics, and high amounts of laboratory time were associated with high grades in college physics. Hart and Cottle (1993) found that high performing introductory college physics students at Florida State University had performed well in high school math and had taken high school physics. Alters (1995) replicated this study at the University of Southern California with 161 students finding similar results.

Each of these studies examined only a few variables and relied upon simple correlations with college grades; however, underlying demographic relationships went unexplored. One finding was that those students who do well in college science often did well in high school mathematics. This result can lead one to believe the two are related, but it could be that having parents with college degrees is a variable with the most predictive power for both college achievement, as well as taking high school math. Regression techniques are routinely employed to reveal underlying relationships hidden by such covariates (Lee, 1983; Reynolds & Walberg, 1992).

Two studies have investigated the relationship between student background and college performance, employing regression techniques that seek to explain the variation in physics grades. Champagne and Klopfer (1982) tested 110 University of Pittsburgh physics students for their ability to predict the outcomes of physics demonstrations, their math skills, and their ability to reason logically. Demographic data were collected on each student, along with the number and type of science and math courses previously taken. Analyzed using multiple regression, the data revealed that high school math courses and physics—even advanced placement (AP) physics—were *not* significant factors in predicting student performance. Only performance on the specialized tests of preconceptions was found to be a significant predictor. Halloun and Hestenes (1985) investigated predictors of introductory college physics grades for 1,500 Arizona State students as part of a larger study of student conceptions. Similar to the findings of Champagne and Klopfer, math and physics pretests were the best predictors of college performance, while high school courses in math and science had statistically significant but minor effects. So, small studies have reached different conclusions when they account for different variables.

No studies connecting college physics success to high school physics background which use multiple regression technique to examine a large number of possible predictors were found in the literature. Surprisingly, the relationship between innovations espoused by many science educators (use of extended labs, project-based learning, more qualitative textbooks, constructivist pedagogies, alternative assessment, AP courses, and teacher demonstrations) and later college physics success have not been investigated in this manner. Although others have compared high school and college course curricula, the nature of the high school pedagogy is left unexamined in these studies (Bates, 1993; Nordstrom, 1990). As a result, there is very little research that can help teachers and students make specific pedagogical and curricular decisions. We have taken the view that it is essential to explore alternative, especially demographic explanations, for student success. Poorer communities may not offer physics with the frequency or the variety of wealthier communities. College-educated parents may highly encourage their children to take high school physics. Not accounting for demographic variables can artificially inflate the apparent relationship between preparation and later success in science.

In attempting to account for the variance in a restricted student population, relying on a unique student body or grading practices of a single instructor may confound any analysis. It is essential to examine performance at many colleges and universities to make a legitimate argument for the generalizability of results.

METHODS

The methods used in this study may seem unfamiliar to most scientists and science teachers.[2] Educational experiments only rarely have full control over variables or the ability to randomly choose or assign subjects. In this sense, the methodology for this study is considered epidemiological rather than experimental. We relied on the natural variation in the experiences, background, and decisions of a sample of college students rather than explicit comparison of treatment and control groups (Tiwari & Terasaki, 1985).[3] For example, our sample varied greatly in the kind of high school physics courses students had, as well as their demographic background.

Epidemiological studies have the power to test simultaneously the strength of many hypotheses for which empirical trials could never be performed. Controlled follow-up studies can then establish with increasing certainty the apparent causal connections revealed by the epidemiological surveys. We understand that our study cannot claim causal connections between variables and outcomes, but it can identify key relationships that are worthy of controlled studies. For this reason, our results must be viewed with caution. Yet, a small or negative correlation can be considered evidence for a lack of causality.

The Survey Sample

Expanding from a methodology of only studying one institution at a time, the authors wished to sample the full variety of college physics courses and of students taking these courses. Students in introductory college physics courses nationwide come from many different high schools and do not have identical backgrounds in physics. Likewise, high school physics teachers do not know where their students will go to college or the particular physics course that they will be able to take there.

According to a national study by the American Physical Society (Neushatz & Alpert, 1994), approximately 360,000 students took introductory physics at the college level in 1993. We hoped for a wide geographic distribution, so regional influences would be minimized, and for proportional representations of so-called “college” physics (algebra-based) and “university” physics (calculus-based). We expected a wide range in class sizes and a variety in textbooks. We desired a reasonable ratio of private to public institutions and to include four-year colleges and universities.

Through mailing and follow-up phone calls to 100 randomly selected college physics professors at four-year colleges and universities,[4] 38 were identified as teachers of an introductory college physics course. Six did not wish to participate in the study. After the 2 years of preparation for this study, eight more professors no longer were teaching an

[2] One anonymous reviewer commented “[in this article] there are many uncontrolled variables, and the reliance of students to accurately recall and report on their physics experiences is a serious weakness . . .”

[3] This is the method by which neural tube defects in newborns was found to be related to insufficient dietary intake of folic acid. Folic acid is now a required supplement during pregnancy. (Elwood et al., 1992).

[4] From a list secured from Market Data Retrieval in Shelton, CT.

introductory course.[5,6] Five professors withdrew from the study during the fall semester, four cited that they did not have enough time to distribute and collect questionnaires, and one reported that students objected to sharing their grades with us. All together 19 courses (18 colleges) with 1,933 students made it into the final sample.[7]

These colleges represent a variety of affiliations: nine public state institutions, eight private institutions, and one national military academy. Nine of the courses are calculus-based, so-called "university" physics; ten are algebra-based "college" physics. Fifteen are universities, three are four-year colleges. Course sizes range from 21–292 students, with a mean of 97. Fifty-three students did not receive grades in their course, either dropping out or receiving incompletes. These students were not included in the grade-based analyses, but their answers were included to profile the high school experiences of students.

The Instrument

Both qualitative and quantitative methods were used in preparing our written instrument. Reviewing the general literature on science learning helped to identify possible variables for measurement. Previous studies have examined the impact of student-centered instruction (Sandler, 1992), textbook use (Holdzkom, 1985), teacher demonstrations (Hynd, 1994), laboratory and project work (Unruh & Cooney, 1985; National Center for Educational Statistics, 1995), the use of qualitative and quantitative problem solving (Mazur, 1996), student-focused discussion and misconceptions (Clement, 1993; National Center for Educational Statistics 1995), mathematics background (Maple, 1991), teacher characteristics (Anderson & Mitchener, 1993), topic selection (Hoffer, Quin, & Suter, 1996), and content reduction (Rutherford & Ahlgren, 1990). We followed up our literature review with in-person and telephone interviews of a dozen physics teachers and college professors, asking them to identify the variables that they thought had the greatest impact on student performance in college physics. Teachers generated additional hypotheses that were not found in the literature, one topic that surfaced repeatedly was the role of "coverage." Many teachers characterized the classroom as a place where students became familiar with the entire breadth of physics, so there would be no surprise topics later on in their college courses. Others felt that depth was more important and chose to concentrate on only a narrow range of topics in physics.

Within the literature on high school-to-college transition, several demographic variables are found to account for some of the differences in performance and in course-taking behavior:

- gender (Kahle, 1992; Maple, 1991; Linn & Hyde, 1989)
- race (Maple, 1991)
- parents' education (National Center for Educational Statistics, 1992, 1995)

[5] An additional five professors used the questionnaires with their spring courses. It was felt that these courses were generally not in the main sequence of physics classes either covering advanced materials or made up of students who had problems in other courses. They were not included in the current analysis.

[6] This study could be biased in favor of courses in which the professor has taught for at least 2 consecutive years since no professor teaching for the first time could have been included in our selection process.

[7] Colleges: Christopher Newport College, USC Coastal Carolina College, Drury College. Universities: Auburn University, Bucknell University, Frostburg State University, McMurry University, North Carolina Central University, New Jersey Institute of Technology, New Mexico State University, the State University of NJ at Rutgers, University of South Carolina, University of Utah, Wake Forest University, University of Washington, University of Wisconsin (2), Villanova University, and the United States Coast Guard Academy.

- school size, whether it is public or private, and school affluence (National Center for Educational Statistics, 1995; Neuschatz & McFarling, 1999)
- school course offerings (Neuschatz & McFarling, 1999) and prior coursework taken by students (Kaufman, 1990)

Attitude measures were not included as predictive variables. Attitude is simply too closely tied to performance as an outcome variable. Moreover, many studies have examined the relationship between attitude and performance (Debaz, 1994; House, 1993; Lawrenz, 1976), leading to a finding that attitude should generally be treated as an outcome measure in a study such as ours, since achievement better predicts changes in attitude rather than attitude predicting achievement.

We also wished to choose a reasonable gauge of success in introductory physics courses. This was a key decision; either we could choose to rely on the grades awarded by professors or develop our own measures. On one hand, academic grades are the most obvious choice, given that a professor's view is the most appropriate measure of student understanding. Yet, many in the educational community dispute that such grades can assess a "true understanding" of physics. We chose not to hold ourselves above the level of college teachers, but to accept their evaluation of their students at face value. It is the professor that gives feedback in the form of grades to his or her students as to whether they understand the physics taught and whether they should pursue study or not. We recognize that academic grades in introductory college courses are not the only standard for measuring the fruition of precollege preparation, but grades are an accessible and universally measured variable. The reader should not interpret our findings to represent the amount of physics a student has learned. Rather, our analysis predicts how well a student performs in comparison to others in his or her college physics class. This study identifies the significant differences between college physics students who earn high grades compared to those with low grades. We also explore the opinions of college physics students concerning the degree to which they felt that a high school physics course helped in their college physics course.

Based on our literature review and teacher interviews, we initially constructed a 52-item pilot instrument for the purpose of testing wording and format. This instrument was administered to 112 students taking physics in two universities in the Boston area. The results were compiled and used to modify the survey instrument: numerical and qualitative scales were adjusted to help distribute student responses more evenly so as to increase the variance in future data. Confusing or unanswered questions were eliminated or reworded.

The final survey contained 57 questions (see appendix). Begun in the spring of 1992, we took over a year to develop the final survey instrument. Survey data were collected in the fall of 1994 and have been analyzed in several ways since then. Professors distributed the survey to all students to complete during class time early in the term. Professors recorded the grade of each student on the forms and returned them at the end of the term. All forms were examined for completeness and checked for coding accuracy.

Data and Analysis

Descriptive statistics (counts, frequencies, means, and standard deviations) were calculated for all variables. Both contingency tables and correlation matrices were constructed to search for patterns in the data. Ultimately, all variables were mapped to metrics, some by the use of dummy variables (e.g., use of a textbook or no use of a textbook) so that multiple linear regression could be used as the primary analysis tool.

We were guided by Pearson correlations and factor analysis in combining related variables into an *index* that reflects an underlying construct (Bohrnstedt, 1994). Two indices were constructed from highly correlated variables. High school grade point average (GPA) was estimated by averaging the last grade reported in high school science (other than physics), mathematics, and English courses. Parents' education index was constructed from the reported father's education and mother's education. In addition, two variables were constructed from information gathered in our survey. One identified those students who have a professor in college physics of their own gender. The other characterized the level of difficulty of their high school physics text based on its mathematics level and whether it was considered a college or university level text.

We understand that studies that rely on survey instruments must pay careful attention to the degree to which subjects can accurately recall past experiences. As a result, we turned to research that also used these instruments. The medical and psychological community make regular use of such self-reporting for collecting data. Horan et al. (1974) found that the veracity of subjects can be affected by a wide variety of factors, including the risk involved in accurate reporting. Yet, self-report surveys (even concerning such touchy subjects as drug usage) can be reasonably reliable (Oetting & Beauvais, 1990). Our survey prompts for recall of the frequencies of events decomposed into several specific categories. These more easily interpretable quantitative scales are preferred over subjective choices (e.g., we ask students to estimate the number of weeks they studied mechanics rather than judge its relative importance compared to other topics; we then used these estimates to establish the comparative scales). Such a strategy increases the accuracy of self-reports by decreasing the cognitive effort required (Menon & Yorkston, 2000). The shape of the "forgetting curve" is very nearly linear for recall of information similar to that which we collected (high school teachers' names), remarkably decreasing at a rate of only 3% each year in a study lasting 12 years. Bradburn (2000) explains that recall of this information encoded in an organized fashion can be quite reliable, especially if contextual cues are included.

Our survey subjects ranged in time since they had high school physics from less than one year (as freshmen) to four years (as seniors). To examine the accuracy of recall, we compared the distribution of variables with which the students have current knowledge (parents' education) and those which they experienced in high school (e.g., lab freedom and physics teacher's friendliness). Comparing currently available knowledge with recalled knowledge, mean ratings by year in college were remarkably stable (see Figure 1). There was a slight decline in means over four years. The increase in the 95% confidence intervals (± 2 SE) was due to a decrease in the number of subjects taking introductory physics in college over the four years. The standard deviations of each distribution were remarkably stable, lending support to the view that the accuracy in recalling the information in which we had an interest does not diminish significantly over the four years of college.

RESULTS

We describe here a range of results, initially calculating descriptive statistics that aided in characterizing our sample. Two regression models are constructed. The first model includes both students with and without high school physics backgrounds. The second model examines the differences in the subset of only students with high school physics backgrounds.

Descriptive Statistics

Professors grade their students using several schemes. Many schools restrict their grades to whole letters (A, B, C, D, or F) without plus and minus (e.g., B+ or B−); others include

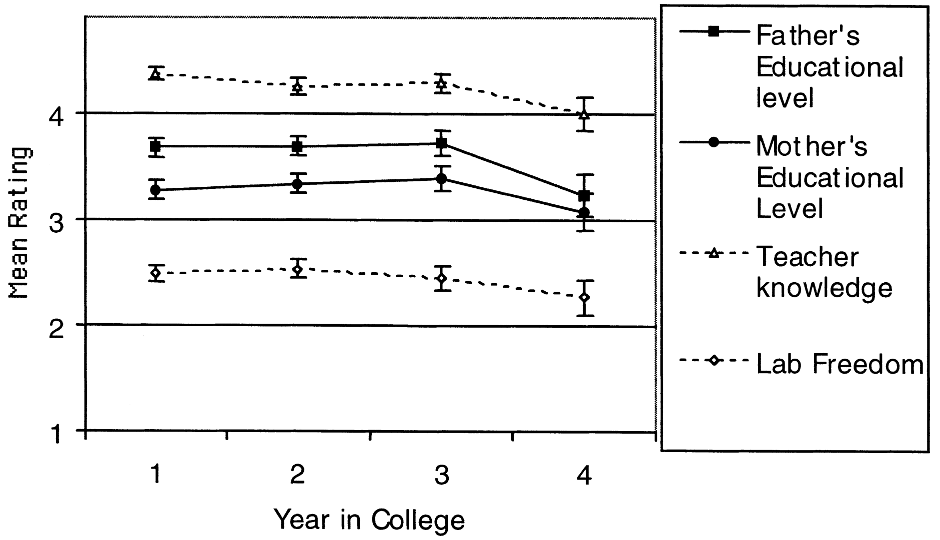

Figure 1. Accuracy of self-report. This graph compares the mean responses of surveyed students to four questions as a function of their year in college. The accuracy of self-reports may decline substantially as time passes. Freshman physics students have been out of high school for less than a year, while seniors for much longer. No large change in item means is observed between items that are based on current knowledge (parental education) and those which are recalled from high school. The average yearly increase in standard deviations in response to these four questions is small (only 1%) showing that the pattern in answering changes little with college year.

them. Some schools grade on a 100-point scale. We converted each scale to a 100-point scale (A = 95, A− = 91, B+ = 88 . . .). Student grades in their college courses have a mean of 81.8 (B−) out of 100 with a convenient standard deviation of nearly 10 points (9.94 or a whole letter grade). Figure 2 shows the data parsed into two groups, those who took high school physics (with a mean of 82.1 ± 9.9) and those who did not (with a mean of 79.8 ± 10.2); this difference (with a t-test significant at the $p = .001$ level) represents an effect size of 0.24 SD (see also Sadler & Tai, 1997).

Students come from a wide variety of backgrounds—84% are from public schools. White students make up 78% of the sample, those with Asian backgrounds, 11%. African-American and Latino students each represent 4% of the sample, Native Americans only 0.5%. Two-thirds of the students in the sample identify themselves as male. Roughly one-third hail from the suburbs, while one-quarter each are from small cities or small towns. Fourteen percent are from large cities and only 6% from rural areas. The majority (63%) of students took calculus in high school and 87% previously took both chemistry and biology. The high school GPA of students (based on last science, math, and English courses taken) is 89 ± 8 (±1 SD). Students' parents vary in their level of education. Sixty percent of student's fathers have four or more years of college, while this is true of 45% of mothers. Only 4% of students have mothers or fathers who did not complete high school.

Almost all college physics students come from high schools offering physics (94%). Of the 293 students without high school physics, 52 are from schools in which physics was not offered, while 241 come from schools where physics was offered. Roughly half of the students in the sample had "regular" high school physics. About one-sixth each took AP, honors physics, or none at all. Only 12 students identified their high school course as primarily for nonscience students. Most students who took physics had a 1-year course, although 13% of the sample had 2 or more years of high school physics. These students

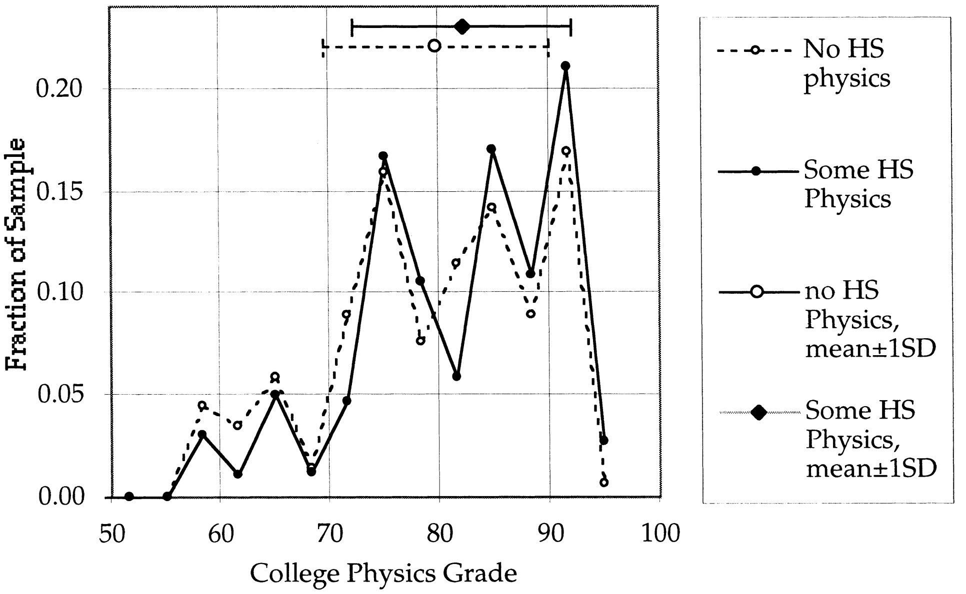

Figure 2. College grade distribution. The grade of every student in the sample was converted to the same 100-point scale. Students who did not take a high school physics course are shown as open circles connected by a dotted line. Mean college physics grade of those who have not taken high school physics is 79.8 compared to a mean grade of 82.1 for those who have taken high school physics.

were twice as likely to take AP physics in their second year as compared to a non-AP course.

Using our findings, one can further characterize the backgrounds of college physics students. Of the 2,398,000 students who graduated from high school in 1994, 660,000 (24.7% of high school graduates) took a high school physics course (NSF, 1995). At four-year colleges and universities with a total annual physics department enrollment of 1,100,000, students who took an introductory physics course number 360,000 (32.7% of college students).[8]

This transition in physics enrollment is graphically displayed in Figure 3. Combining the previous statistics, 45% of students who have taken high school physics course go on to take a college level physics course, while only 3% of students who have not taken high school level physics go on to take it in college. Virtually all AP students and 70% of those in honors courses take an introductory college physics course. The rates are lower for those in regular high school physics courses (only 30%). For students who take a high school course aimed at nonscience students, their rate of enrollment is the same as those who have not taken high schools physics at all (3%).

Multiple Regression Models

Various hypotheses suggested by the literature, the authors, and the participating physics teachers were compared using multiple linear regression models. Each model was built

[8] Private telephone conversation with Michael Neuschatz, American Institute of Physics, College Park, MD (7/16/96). This number may be a low estimate since colleges without physics departments and physics courses outside of physics departments are not included.

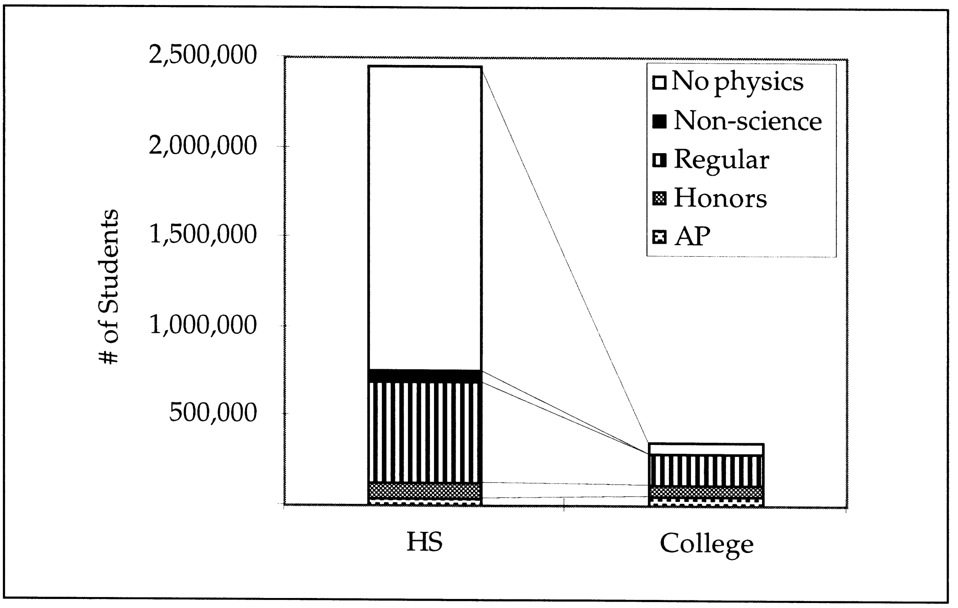

Figure 3. High school to college transition in physics. College enrollment in introductory physics is roughly half that of high school physics. College courses draw their enrollment unequally from students who have taken different high school courses in physics. Most students who take honors or AP physics as their highest physics course in high school take physics again in college.

using reverse stepwise regression, starting with all variables and removing those with the lowest level of significance. The set of excluded variables was tested for significance at each stage. The final model contains only variables that are significant at the $p = .05$ level.

Model A: Accounting for Differences in High School Physics Enrollment. Model A (see Table 1) predicts college physics grades based upon which kind of physics course students had in high school (or not). Demographic variables and the college attended are used as controls. In the 19 courses, mean grades varied between a high of 94.2 to a low of 74.3. It is not the intention of this study to in any way explain the difference in grades among colleges, only the grades earned by students within a college course. We control for the effect of differences between courses by entering each college as a separate variable in each model.

Thirteen variables are found to be significant at the $p = .05$ level and were chosen for this model. The metric coefficient provides a way to interpret the effects of the variable on course grade directly, for example coming from a suburban school accounts for an additional 0.93 points in grade, controlling for other listed variables. The standardized coefficient allows a comparison of the relative importance of variables within the model (e.g., race and AP coursework are the most important predictors). The first five variables (race, each parent's education, type and location of school) are all related to student socioeconomic status (SES). When the gender of the college professor teaching introductory physics is the same as the student (e.g., professor and student are either both female or both male), students averaged 1.58 points higher than when they are of opposite gender of the professor. Having a professor of the same gender may also play a role in retaining underrepresented groups in a science major (Seymour & Hewitt, 1997). The enrollment

TABLE 1
Model A and B. Multiple Regression Models for College Grade in Introductory Physics. Model A Includes All Students with Complete Questionnaires; Model B, Only Students Who Have Taken a High School Physics Course.

		Model A		Model B	
	Missing students	130/1933		335/1640	
	R_2	25.80		35.50	
	R_2 adjusted	24.60		33.70	
	College or university	included		included	
	Variable	Metric	Std.	Metric	Std.
	Constant	41.18**		25.53**	
Demographics					
1	Private high school	−1.67**	−0.06		
2	Suburbs	0.93*	0.04	1.18*	0.06
3	White	3.62**	0.15	2.41**	0.10
3	Asian	3.37**	0.10	2.92*	0.09
5	Male			−2.01*	−0.10
55–56	Parent's education (≤HS, HS, <4 yrs college, 4 yrs, >4 yrs)	0.64**	0.07	1.01**	0.11
Student Decisions					
57	College year (F, S, Jr, Sr)	1.01**	0.10	1.30**	0.13
	Prof. gender is same as student	1.58**	0.07	3.74**	0.17
44	Took calculus in high school	2.58**	0.12	2.47**	0.12
47–49	HS GPA ($A = 5$, $B = 4$, . . .)	0.36**	0.02	0.43**	0.03
8	Regular physics	2.26**	0.11		
8	Honors physics	3.51**	0.14		
8	AP physics	4.32**	0.15		
7	≥2 years of physics	2.80**	0.10	3.05**	0.10
Teacher Decisions					
46	Physics grade ($A = 5$, $B = 4$, . . .)			0.13**	0.11
42	Friendliness			−0.55*	−0.07
34	Coverage			−0.49*	−0.05
43	Explains problems inseveral ways			0.77**	0.09
11	No text used			4.31*	0.06
15	Mechanics in weeks			0.12**	0.10
21	Labs/month			−0.28**	−0.07
14	% Text in % of book covered			0.03*	0.06
13	Reading in minutes/day			−0.04*	−0.05
26	Qualitative problems/class			−0.42**	−0.09
28	Discussion after demonstration			−0.04*	−0.05

*($p \leq 0.05$)
**($p \leq 0.01$)

year in which college physics was taken played a role in college grades, with higher grades resulting as the number of years enrolled in college increased.

Our data show that college physics grades are related to the kind of high school physics course taken. A "regular" physics course had the smallest association, followed by an honors physics course. AP physics had the largest association of the group. Taking a physics course for 2 years in high school was also significant. Taking a high school course in calculus appeared to have as much of a relationship to the college grade as did taking a regular physics course.

The regression coefficients are additive and the grade can be estimated for a variety of combined variables. For example, students who take a high school regimen of a first year of physics, followed by a second year of AP physics and calculus are predicted to attain a 9.7 point advantage (a full letter grade) over those not taking physics and calculus in high school.

Five variables are surprisingly absent from this model and are not significant at the $p = .05$ level:

- high school size
- physics offerings (regular or AP physics)
- whether students took high school chemistry and biology
- student participation in science fairs
- student gender

Taking high school physics appears to have a weaker relationship with college physics grades (accounting for demographic variables) than in the previous studies (Alters, 1995; Gifford & Harpole, 1986; Hart & Cottle, 1993), but there is still much variance in college grades that remains to be explained.

Model B: Accounting for Differences among High School Physics Courses. We have attempted to account for additional variance by constructing Model B, which is based upon a reduced set of students who have all had high school physics. We examine each of the variables that made each of the courses that they took a bit different. This model allows for a close look at which of the attributes of high school physics predict performance in college (Table 1).

Twenty-one variables (out of 69) were found to be significant at the $p = .05$ level. We grouped them into three categories: demographics, student decisions, and teacher decisions. Together they accounted for about one-third of the variance in grade.

Among the demographic variables, it was found that white and Asian students did better in their college courses, as did women than men with the same background. SES factors included parents' education and if the high school was in a suburb.

Student decisions played a major role in their college grade. Maintaining a high GPA in high school and doing well in high school physics predicted higher grades in college physics. Students who took college physics later in their college career and who had a professor of the same gender received higher grades.

The factor we consider most important in Model B compared to Model A is that the level of rigor of the physics course taken in high school was no longer significant when specific teaching methods were included in the model. The variance explained by regular, honors, and AP courses were subsumed in the variance explained by the decisions made by teachers in their high school physics courses. To put it another way, the variation in high school physics courses was better explained by these additional variables than by conventional categorizations of regular, honors, or AP.

High school teacher's decisions were related to future student grades in college. These new variables that are related to higher grades in college are:

- teachers described as explaining problems in several different ways
- using no textbook at all or reading it less[9]
- courses characterized by students as covering a small number of topics in great depth (particularly concentrating on mechanics)
- deemphasizing the solving of qualitative problems in class
- carrying out four labs or fewer each month
- students with teachers described as of average friendliness or less
- avoiding extensive discussions following demonstrations

Twelve popular physics textbooks were listed from which students could choose the one they used in high school. Only 188 students (10%) were able to identify their high school text from a list of titles and authors. None of the texts were found to have a significant association (at the $p = .05$ level) to college level grades, neither did the role that the text played in their high school course.

An additional set of models was constructed to predict the degree to which students thought that high school physics helped in college physics. The average predicted impact of a high school course in physics was an additional 7.8 points (out of 100 total) added to the college grade. Among the significant predictors of this advantage were that males thought high school physics helped more, along with more quantitative problems, successful prediction of demonstration outcomes, friendly high school teachers, extensive coverage of electricity and magnetism, and larger class sizes. Those who had not taken high school physics attributed significantly more value to taking a high school physics course than those who had actually taken one.

DISCUSSION

This study identified variables predicting performance in introductory college physics in a carefully selected sample by testing a variety of plausible hypotheses. Several variables have great predictive power, while others have little. Control variables, including students' high school GPA and SES account for a substantial portion of the variance in college grades. Decisions made by the student and by their high school physics teacher appeared to also impact student grades in an introductory college course.

Comparison to Previous Studies

We find that taking high school physics was related to better performance in introductory physics at the college level. The size of this relationship was one-third of what most students believe and one-half of that found by previous studies (Alters, 1995; Hart & Cottle, 1993; Gifford & Harpole, 1986). Why has our study produced results that are so different (see Table 2)? Two technical explanations come to mind.

First, we have modeled student preparation by identifying many different relevant preparation and demographic variables that were highly correlated with taking high school physics. Prior studies primarily compared the college physics grades of those students with and without high school physics using a *t*-test to calculate significance. While this is a

[9] The only variable confounding this pattern was that students who reported getting through a larger fraction of the textbook did better in college. Postsurvey interviews with students revealed that many interpreted this question as to whether they reached any of the later chapters in the text, not as the proportion of the chapters actually studied.

helpful first step in analysis, it is unreasonable to attribute differing performance to a single variable alone, since other variables may be even better predictors of performance. Exploring alternative hypotheses reflects a stronger methodology (as in science) and increases confidence in the model. For example, taking a calculus course in high school is highly correlated to doing well in college physics ($R = 0.179$), as is taking a high school physics course ($R = 0.133$). Accounting for only taking high school physics inflates the predicted college grade, since taking physics and taking calculus in high school are correlated with each other ($R = 0.283$). A more accurate estimate of the predictive value of a high school physics course is produced by including relevant covariates in the regression model.

The second possible reason for differing results was that our student sample was larger and more diverse than those used in prior studies. By randomly selecting our sample classrooms, we are more confident of having a representative sample of the physics-taking population. Since our study makes use of more students, the standard errors in our regression coefficients tend to be smaller. For example, Hart and Cottle found a 6.02 difference in the college grades in favor of high school physics takers (± 1.09 SE) with an adjusted R^2 of 5.9%. Our study showed a 3.49 point difference (± 0.57 SE) with an adjusted R^2 of 1.7%.

Among the possible reasons for learning science in U.S. classrooms, the most common goal espoused by teachers is academic preparation for future courses (Hofwolt, 1985). Teachers try their utmost to prepare students for college science. Koballa (1989, p. 26) reported the most striking discovery of Project Synthesis, the NSTA's extensive study of practices in science teaching: "Preparing students for specific examinations and later coursework appears to be the goal of most science teaching." This conclusion is supported by a 1996 National Center for Educational Statistics report which showed 89% of high school physics teachers feel, "preparing students for further study in science" is a moderate to major emphasis in their courses (Hoffer, Quin, & Suter, 1996). The results of this study raise questions about the degree to which a single high school course in physics contributes in a major way to success in college physics.

Demographics

The range of demographic variables included in this study represents *a priori* situations, conditions that are not the choice of students or their teachers. A student cannot choose his or her race or gender. Students rarely have any control over their family's affluence, the size or makeup of their community, or the educational level of their parents or guardians.

In our study, white and Asian students received higher grades in college physics than blacks and Hispanics. Students from more affluent communities later earned higher grades than those from less affluent communities. A higher level of parental education was pre-

TABLE 2
Key Differences in Prior Studies. Differences in Mean College Grade (100 Point Scale) Found in Introductory Physics in Three Prior Studies and in This Study.

Difference Between	Hart & Cottle	Alters	Gifford	Sadler & Tai
None and some HS Physics	6	5	11	2.4–2.8
High and low math grades	6			5
Few and regular labs			4	−1.7

dictive of higher grades in college physics. Mother's and father's educational levels were highly correlated with each other ($R = 0.543$). Especially in the case of students with fathers who had not finished high school; the mean college grade in physics was 77, while 76% of such students have taken high school physics. This correlation is in contrast to that of students whose fathers had a graduate degree; their mean grade was 84 and 98% have had physics in high school.

Neuschatz and McFarling (1999) also found that fewer students from economically poorer communities took physics in high school. Students from poorer communities (disproportionately black and Hispanic) faced a critical shortage of better-prepared and experienced science teachers (Atwater, 1993; Neuschatz & McFarling, 1999). Schools in poorer communities were less likely to offer AP physics, had budgets averaging 40% less for equipment and supplies, and were far less likely to have a teacher who exclusively teaches physics (Neuschatz & McFarling, 1999). Economic and racial factors were difficult to disentangle in a study such as this, but it is clear that the opportunities offered to students in poorer communities do suffer. In our study, the kind of community and level of parents' education were both significant predictors of whether AP physics was offered in the students' high school, while race was not. The inequities of the U.S. educational system even showed up among the most talented students in our colleges. The socioeconomic background of students in introductory college physics played out dramatically in the grades they received. As Neuschatz and McFarling (1999) pointed out,

> . . . even in the relatively restricted confines of high school physics, there is essentially a two-tiered educational system. The upper tier does a creditable job of offering science-oriented and academically well-prepared students an introduction to physics. The lower tier, in contrast, faces all sorts of impediments, including teachers who have less preparation . . . substandard facilities . . . [and] less funding for labs and supplies. . . . (p. 36)

This disparity made it all the more important for physics teachers in less affluent communities to make use of pedagogies and materials that could help improve their students' success in college physics. While students from more affluent backgrounds appear to survive well in college physics, those from poorer circumstances are more in need of the "leg up" that a strong high school preparation can provide.

Student Decisions

Students can make decisions, in both high school and college, which appear to impact their grades in college physics. In high school, they can take a calculus course, maintain a high GPA, and choose a rigorous sequence of high school physics, for 2 years if possible. At the college level, seeking out a professor of the same gender and taking introductory physics later than the freshman year were found to be related to better performance in college physics. Some students avoid rigorous math and science courses in high school, believing that earning lower grades in these courses will decrease their chances of being admitted to the college of their choice. This strategy can backfire later when a strong preparation in science may be of benefit.

Calculus, typically the most rigorous of high school mathematics courses, has roughly the same metric coefficient as a year of regular physics or a second year of physics. Students who work hard to achieve high grades overall in high school tend to get higher grades in college physics. These two markers, calculus and high grades in high school, predict higher than average grades in college physics, bringing into question the policy of restricting students from enrolling in college physics unless they had an earlier course. This is not to deny the role of students' decisions to engage in a rigorous sequence of high school physics. Students who take regular physics, then AP physics for a second year, average grades 9.4 points above those of their classmates without any high school physics.

Two factors pertaining to a student's decisions in college are related to grades in college physics. College students can take introductory physics during any of their 4 years. Those students who wait until their sophomore or junior years perform one point higher for each year they wait after their freshman year. The gender of a student's college professor also makes a difference in student grades when seen in relation to the student's gender. Three professors out of 19 in our study are female. Students with professors of the same gender did significantly better in college physics. Women achieved 3.16 points better with female than male professors. Quite possibly, women may see their female professors as role models, feeling less out-of-place in a classroom usually dominated by males (Kahle, 1990). Yet, it is doubtful that the pedagogy of female professors differed significantly from that of males (AAUW, 1992; Kahle, 1990).

Teacher Decisions

The primary goal of this study was satisfied through the building of Model B. Several variables that are related to success in college physics can be decided upon by high school physics teachers.

In constructing a coherent story around the findings, we discovered that many of the variables are related to coverage, an issue with which teachers are very concerned. Higher college grades appear to be associated with high school courses that hold to rigorous standards, but take their time. This approach was characterized as covering few topics in great depth, with teachers that explain problems in many different ways, and with teachers turning from the text as the major guiding force to that of a resource. A considerable portion of the text can be consulted over the course of the year, but there appears to be little advantage to covering it all, spending large amounts of time reading it, or completing a large fraction of text problems. Covering a limited set of topics, dealing primarily with issues in mechanics, appears to be beneficial.

This concentration on just a few concepts should not exclude qualitative problems, but teachers should consider carefully which qualitative concepts to cover. These concepts should be included on tests and quizzes along with quantitative problems. Laboratory experiments should be carefully chosen to tie in with major course themes. Doing fewer lab experiments can be very effective if those performed relate to critical issues and students have the time to pursue them fully. Students benefit when there is sufficient time to reflect on their personal experiences, laboratory findings, and teacher's explanations, mentally reformulating them into more powerful structures (Minstrell, 1993).

Several aspects of high school physics are dear to teachers (as they are to the authors of this study). Classroom demonstrations are a favorite activity of many teachers, yet there appears to be little support to recommend a frequency greater than once a week. Tobias (1990) found that demonstrations are entertaining, but are more often confusing. This study found that extensive discussion *after* a demonstration appears to be counterproductive. Complete discussions should take place *before* the demonstration so that students are invested in the outcome.

Selection of a physics textbook is a very visible decision that a teacher can make and there seems no end to the advertisements and promotional materials that publishers provide to teachers to hawk their products. Authors spend years creating new texts and updating old ones. This study found no significant difference in college physics grades among any of the major texts used in high school physics. While there may be a difference between alternative treatments or topics covered, this study failed to reveal it. In fact, those teachers who choose not to use a text appear to have a real advantage. Perhaps these teachers are freed from the most obvious rubric for measuring how much they have covered and must decide on which central ideas to pursue. Perhaps they use materials that they have written themselves or have been given to them by other teachers or researchers. Students often rely heavily on the authority of textbook, either looking for key words or unconnected facts to answer questions. In contrast, students are more likely to find their answers in class notes or their own real world experiences if the text is not central (Anderson, 1992). In any event, avoiding reliance on a text appears to have a significant association with higher grades in introductory college physics.

The research literature points to a profound "impedance mismatch" between precollege and college science courses' pedagogy and content, in spite of the Herculean preparatory efforts of many high school teachers (Dickie, 1991; Razali & Yager, 1994; Shumba & Glass, 1994; Warkentin et al., 1993). College and precollege teachers differ in the depth and structure of their content knowledge, which may add to the confusion and frustration of students in transition to college (Bates, 1993).

Teachers have different personality characteristics, levels of knowledge, and preferred methods of teaching. Students associate friendly physics teachers with higher grades in college physics, although students with such teachers appear to do significantly worse in college physics. Teachers reported by students as having high levels of physics knowledge or having high teaching ability are certainly appreciated by students, but the patience and gift of approaching problems and topics from many viewpoints appears to be a much more beneficial capacity. Yager (1988) found that exemplary high school science teachers had taken no more college level science courses in their field than those teachers who were having serious problems teaching science. Better subject matter preparation did not appear to have an impact on teacher quality.

Variables That Do Not Appear in the Models

One of the results that begs discussion is the set of variables found to be not significant and hence excluded from our optimal model. These variables add no explanatory power in that their impact was not significant, nonlinear, or better represented by other variables. Correlation coefficients are calculated for these 30 variables against college physics grade (see Table 3). The magnitude and sign of the correlation coefficient measure the degree to which the variable changes linearly with college grade. While a high correlation is not evidence for causality, a low or negative correlation is evidence against a positive causal relationship with college physics performance.[10]

Issues that are typically decided at the school level and not by teachers or students are class size, school enrollment, whether AP physics is offered, and the number of periods each week that physics class meets. Of the four variables, only class size was significant at the $p = .05$ level; students from smaller high school classes did better in college physics. This variable is correlated with others that account for more variance and that appear in the model; for example, suburban schools and AP physics courses are known to have smaller classes.

Students who took biology and chemistry in high school do slightly better in college physics. Those who took a high school physics course aimed at nonscience students do slightly worse. Although statistically indistinguishable from students who take more rig-

[10] We thank an anonymous reviewer for this insight.

TABLE 3
Variables Excluded from the Models. Correlation Coefficients are Calculated for the Thirty Variables Excluded from the Final Regression Equations. Variables are Grouped by Issue.

Choice of Topics		R
16	Electricity and magnetism	0.114**
17	Optics and waves	0.046*
18	Heat and kinetic theory	0.045*
19	Relativity	−0.006
Class Climate		
32	Student preconceptions discussed	0.062**
33	Misconceptions revealed	−0.065**
35	Teacher talk	0.050*
29	Predictions before demonstration	0.046*
27	Demonstrations/week	−0.010
36	Student talk	0.008
Problem Solving		
31	Homework done/night	0.040*
38	Qualitative problems on test	0.023*
30	% of text problems assigned	−0.023*
25	Quantitative problems/class	0.013
School Issues		
9	Class size	−0.049*
3	Size of HS graduating class	0.010
6	AP physics offered	0.010
10	Periods/week	−0.003
Student Decisions		
45	Took biology and chemistry	0.054*
8	Nonscience	−0.024*
Teacher Attributes		
37	Examples	0.045*
41	Teaching ability	0.003
12	Text role	0.003
40	Knowledge of physics	−0.001
Labs and Project Work		
24	Double lab periods	−0.064**
20	Projects/year	0.031*
22	Lab freedom	0.018*
54	Participated in science fair	0.017*
39	Lab problems on test	0.011
23	Lab discussion	0.001

*($p \leq 0.05$)
**($p \leq 0.01$)

orous high school physics courses (on the basis of reported science, math, and English grades), there was no evidence to support the contention that such courses were better at preparing students for college physics than traditional courses.

Professors may notice that students who have covered topics other than mechanics in high school (electricity and magnetism, optics and waves, and heat and kinetic theory) receive better grades in college physics. Rather than explain this correlation as resulting from the study of these particular topics, it appears that these topics are indicative of taking a second year of physics and it is this second year that is more highly associated with later success.

Several variables relating to class climate, which include the degree to which a high school physics course is student-centered vs. teacher-centered, were not included in the model, but were highly correlated with college grades, with an emphasis on fewer concepts and with teachers explaining problems in many different ways.

Solving physics problems, in class or on homework, presents teachers with decisions concerning the fraction of book problems assigned, the amount of homework, and the split between qualitative and quantitative problems. Assigning a large number of homework problems was negatively correlated with college grades; such a strategy may actually be counterproductive for learning physics (in preparing students for college physics) (Maloney, 1994).

Preparing for and conducting laboratory experiments requires extraordinary efforts on the part of high school science teachers who rarely have support personnel to help them. Model B showed that more than one lab per week in a physics course does not appear to be beneficial. Correlations of excluded variables with college physics grades may be interpreted as not lending support for extending labs to two periods, or unequivocally giving students more freedom or discussing labs more. Rather than increasing the proportion of physics courses given over to labs, perhaps labs should be focused on fewer topics, with students able to repeat the most valuable experiences. In addition, college physics courses appear to make little use of the knowledge gained in high school physics labs.

As judged by their students, there appears to be little to recommend that physics teachers have an extended command of the subject or exhibit traditionally accepted "teaching ability." Deciding to cover less in greater depth and not relying on a fixed text appeared to make more of a positive impact.

Some Remaining Issues

As with any research study, many questions remain unanswered and many problems have arisen in the course of our efforts. The selection of our sample of 19 colleges started off as a random sample, but the cooperation of particular colleges was ultimately in the hands of professors. Participation in this study may have been a function of the satisfaction of the professor with his or her own teaching or may have been influenced by a desire to support or find fault with precollege science teaching. Our survey, in spite of pilot testing, still contained a few flaws. For example, the choices that we offered for topics in the high school physics curriculum on average only accounted for 68% of the time in a typical physics course. We had hoped to account for a larger fraction of the time spent covering physics topics.

Students who take AP courses, do well, and skip introductory college physics courses are not represented in the dataset. Estimated at 25% of the students enrolled in AP courses, these missing students could skew the distribution of highest performing students.[11] One could argue that these students represent the cream of high school courses and including only AP students who do not place out of introductory physics invalidates our results; however, reanalysis of the dataset excluding all AP students produces almost identical regression equations, but for the variables which relate directly to taking an AP course or 2 years of physics.

A drawback is that this study was not longitudinal. We rely on students to accurately recall their experiences in high school and attribute causality to the relationships uncovered. We produce models through regression techniques, discovering only those relationships that vary linearly with college physics grades. Relationships that are nonlinear do not become a part of the model. While our final model explains 34% of the variance in

[11] Suggested in conversation with Michael Neushatz, APS. 7/16/96.

college grade, there may be other background variables that would explain more that we did not have the wisdom to examine in our survey. For example, Uno (1988) claimed that the best preparation for college science is not content-based courses, but emphasis on developing study skills and self discipline, coupled with strong math skills.

OPPORTUNITIES FOR FUTURE RESEARCH

Outcome measures other than those that quantify academic performance were not examined in this study. Although many precollege teachers feel that doing well academically is an important indicator of student success (Warkentin et al., 1993), other criteria valued by high school teachers were not examined. Many teachers could see the results of this study as not matching their goals and as inapplicable to their classrooms. Three additional measures that show promise for future studies are: “banking knowledge” to reduce the effort required in college courses; increasing students’ own valuing of their high school science experience; and students’ desire to take future courses in science.

Krajcik (Krajcik & Yager, 1987; Yager et al., 1988) found that previous coursework in chemistry had no impact on student grades in a summer school AP chemistry course, but the amount of tutoring help sought was four times higher for students without a prior chemistry course. This implies that taking high school science may serve to reduce the time and effort needed to perform at a satisfactory level in college courses. One could build on this work by asking students to report on their level of effort (time studying and doing homework, class, section, and study group attendance, and comparisons to other college courses) and modeling these as additional outcome variables.

Gibson and Gibson (1993) asked college students about the adequacy of their high school preparation for introductory college biology coursework. Preparation was measured rather indirectly against six concepts previously determined to be “critical for an understanding of biology” (p. 8). Our study queries students as to the direct impact of their high school preparation on their college science grades. In this way, a legitimate comparison can be made between the magnitude of predictive variables and the students’ own beliefs. Students’ estimates of the impact of a high school physics course was roughly three times the actual effect. This comparison shows that students have a belief in the value of their high school science experience that does not match the measured impact.

Hellman (1992) found that more physics in high school translated into taking more physics courses in college, although he did not take into account any demographic variables such as measures of socioeconomic status.

Many studies have identified ways in which females and ethnic minorities are treated differently in their classes than white males (American Association of University Women, 1990; Gilligan, 1982; Tobias, 1990). Several studies recommend changes—weekly testing, encouraging creativity, emphasis on quantitative and spatial reasoning, “tinkering” with the tools of science, and gaining experience before discussion—that could be made in school practices (Kahle, 1992; Stage, 1976; Steiger & Davis, 1992). Relatively few studies examine the impact of such changes. Reanalysis of our dataset could prove very useful in identifying those practices that appear to have an effect in reducing the disparity between performance of the majority and of underrepresented minorities in science. For example, our study revealed that reducing coverage appears beneficial, on average, for all students; however, if examined by demographic groupings, this coefficient may be different for various groups of students. This type of interaction analysis would help to identify classroom practices that may be of substantial benefit to underrepresented groups in the sciences.

Use of hierarchical linear models (HLM) would allow the effects of higher-order variables, inherent in this nested sample, to be accounted for (e.g., type of college, type of college course, geographic location, and college grading variations). Such analysis may help in assessing the relative contributions of variables at different levels in the population. For example, a recent study found that gender is related to student achievement in Australian schools. However, an HLM analysis found that school level differences were more powerful predictors than gender; that is, gender differences were tiny when differences between schools were considered (Young & Fraser, 1994). We feel that such a reanalysis would help to determine which classroom and school practices account for these gender (and ethnic) differences in achievement by employing HLM.

As a final step, multivariate relationships among the system of variables could be modeled using structural equations. These connections would link many indicators to underlying constructs and help to perceive the relationships between variables. Many models can be compared on the basis of measures of "goodness-of-fit."

CONCLUSIONS

Enrolling in high school physics has a positive, but modest relationship with introductory college physics grades. The association was smaller than several previous studies have found and much smaller than college students assume. Demographic and schooling variables predicted a substantial fraction of the variance in student performance. Colleges with policies that limit or prevent students without high school physics courses from taking college courses should rethink their policies in light of this finding. Students with strong high school academic and math preparation can equal or even outperform students who have taken high school physics.

Students in more rigorous high school physics courses, on average, perform better in introductory college physics; however, there is more variation within these courses than between them. The predictive power of the type of course (regular, honors, or AP) is subsumed by specific pedagogical variables when included in regression models. Students appear to do better in college physics if they have taken rigorous high school physics courses, where their teachers concentrated on fewer concepts, covering less material, but in greater depth. Students in regular physics courses with these same characteristics have equaled or surpassed the performance students in more rigorous courses. In particular, deferring to a textbook for the structure and pace of a high school course was not supported as a viable strategy.

This study failed to find that many strategies favored by teachers and researchers predict success in college physics. Project work, student discussion, concentration on qualitative problems, and frequent laboratory experiments (including open-ended ones) did not predict increased college grades in physics. Perhaps it is the quality of these experiences that have a positive effect and not simply their quantity.

Many opportunities exist for expanding on this study by looking at larger populations, examining the differences among subpopulations of gender and race, and employing more advanced statistical methods.

The authors wish to recognize the efforts of our research assistant, Annette Trenga, in preparing and organizing the survey. Our original collaborator, Professor Alan Lightman of MIT, helped to formulate and carry out our pilot study. He continues to provide us with guidance. Larry Suter of the National Science Foundation, Gerald Hart of Florida State University, and Michael Neuschatz of the American Physical Society supported us with valuable feedback and enthusiasm for our efforts. Colleagues at the Harvard-Smithsonian Center for Astrophysics who provided valuable assistance were Irwin Shapiro, Bruce Gregory, Susan Roudebush, Harold Coyle, Bruce Ward, and Judith Peritz. Graduate School of Education colleagues we wish to thank are Terry Tivnan, Brian Alters (now at McGill University), and Vito Perrone. Most of all, we thank the college physics professors who collaborated on this project and their students, who gave of their time to answer our questions.

APPENDIX I

Physics Performance Factors Student Questionnaire

Researchers at the Harvard-Smithsonian Center for Astrophysics are interested in your experiences in learning physics. We are asking college physics students to fill out this questionnaire to help us find ways to improve high school physics courses for future students. Make your best estimate for each item and answer as many questions as possible. Thank you for your help.

Use a No. 2 pencil only. Erase any stray marks completely.	CORRECT MARK	INCORRECT MARKS
	●	⊘ ⊗ ◒ ⊙

University ______________ (Please print)

Student's Name or I.D. Number ______________ (Please print)

Concerning the last high school that you attended:

1. **What type of school did you go to?**
   ○ Private ○ Vocational ○ Public ○ Private Parochial
2. **In which size community was it located?**
   ○ Large city ○ Suburbs ○ Rural area ○ Small city ○ Small town
3. **What was the size of your graduating class?**
   ○ Less than 25 ○ 76-200 ○ More than 400 ○ 26-75 ○ 201-400
4. **What is your racial background?**
   ○ Black ○ Hispanic ○ Native American ○ White ○ Asian ○ Other
5. **What is your gender?**
   ○ Male ○ Female
6. **Which physics courses were offered in your high school?**
   ○ None ○ General and AP Physics ○ General Physics only ○ AP only

Concerning your last high school physics course:

7. **How many physics courses did you take in high school?** ***If your answer is none, skip to question 44.***
   ○ None ○ 2 years ○ 1 semester ○ More than 2 years ○ 1 year
8. **Was your last physics course:**
   ○ Regular first-year Physics ○ Especially for non-science students ○ Honors ○ Advanced Placement

For Professor's Use:
○ A+ ○ A ○ A- ○ B+ ○ B ○ B- ○ C+ ○ C ○ C- ○ D+ ○ D ○ D- ○ F ○ Inc.

(0) (0) / (1) (1) (1) / (2) (2) / (3) (3) / (4) (4) / (5) (5) / (6) (6) / (7) (7) / (8) (8) / (9) (9)

9. **How many students were in your physics class?**
   ○ 10 or fewer ○ 16-20 ○ More than 25 ○ 11-15 ○ 21-25
10. **How many periods did your physics class meet each week?**
    ○ 1 or 2 per week ○ 4 per week ○ More than 5 per week ○ 3 per week ○ 5 per week
11. **Which textbook did you use?**
    ○ Physics (Giancoli)
    ○ PSSC Physics (Haber-Schaim)
    ○ Fundamentals of Physics (Halliday & Resnick)
    ○ Conceptual Physics (Hewitt)
    ○ Introductory Physics (Keller)
    ○ Physics, A World View (Kirkpatrick)
    ○ Physics: Principles and Problems (Murphy & Smoot)
    ○ Project Physics (Rutherford)
    ○ University Physics (Sears)
    ○ College Physics (Sears and Zemanski)
    ○ Physics: Its Methods and Meanings (Taffel)
    ○ Modern Physics (Williams)
    ○ Other text ○ Harvard Project Physics
    ○ I don't remember ○ Physics: Fundamentals & Frontiers (Stollberg & Hill)
    ○ No textbook
12. **How large a role did your textbook play in your high school physics course?**
    Not used very much (1) (2) (3) (4) (5) Followed it closely
13. **How much did you read the textbook both in class and for homework each day?**
    ○ 0 minutes ○ 20 minutes ○ More than 40 minutes ○ 10 minutes ○ 40 minutes
14. **What fraction of your textbook did you get through during your last physics course?**
    ○ 0% ○ 40% ○ 80% ○ 20% ○ 60% ○ 100%

How much of each of the following topics did you have in your physics class?

15. **Mechanics**
    ○ None ○ 1 month ○ 1 year ○ 1 week ○ 1 semester
16. **Electromagnetism**
    ○ None ○ 1 month ○ 1 year ○ 1 week ○ 1 semester
17. **Optics and Waves**
    ○ None ○ 1 month ○ 1 year ○ 1 week ○ 1 semester
18. **Heat & Kinetic Theory**
    ○ None ○ 1 month ○ 1 year ○ 1 week ○ 1 semester
19. **Relativity**
    ○ None ○ 1 month ○ 1 year ○ 1 week ○ 1 semester
20. **How many times per year did you carry out projects of your own design for physics class?**
    ○ Never ○ Twice ○ More than 3 times ○ Once ○ 3 times

Concerning laboratory experiments that you performed in your high school physics class:

21. **How many laboratory experiments did you do each month?**
    ○ None ○ 1 ○ 2 ○ 4 ○ More than 4
22. **How would you characterize the freedom you had in carrying out your labs?**
    Had to follow step-by-step instructions (1) (2) (3) (4) (5) Free to design investigations and procedures
23. **How much discussion about the lab did you have after it was over?**
    ○ 0 minutes ○ 20 minutes ○ More than one period ○ 10 minutes ○ 40 minutes
24. **What fraction of your labs involved more than a single class period?**
    ○ 0% ○ 40% ○ 80% ○ 20% ○ 60% ○ 100%

Concerning problems solved both in class and as homework:

25. **How many problems did you solve using math?**
    ○ None ○ 3 per day ○ 0 to 1 per week ○ 6 per day ○ 1 per day ○ More than 6 per day
26. **How many problems did you solve that did not require math?**
    ○ None ○ 1 per day ○ 6 per day ○ 0 to 1 per week ○ 3 per day ○ More than 6 per day

Concerning the demonstrations your teacher carried out for the entire class:

27. **How many times each week did your teacher demonstrate a concept or phenomenon?**
    ○ Less than once ○ Twice ○ Four times ○ Once ○ Three times ○ More than 4 times
28. **On average, how long did you discuss each of your teacher's demonstrations?**
    ○ 0 minutes ○ 20 minutes ○ More than one period ○ 10 minutes ○ 40 minutes

29. **Roughly, what percentage of the time did you make predictions of the outcome of demonstrations?**
○ 0% ○ 40% ○ 80%
○ 20% ○ 60% ○ 100%

30. **On average, what fraction of textbook problems did you do for each chapter covered?**
○ 0% ○ 40% ○ 80%
○ 20% ○ 60% ○ 100%

31. **How much physics homework did you do each night?**
○ 0 minutes ○ 20 minutes ○ More than 40 minutes
○ 10 minutes ○ 40 minutes

Concerning the depth in which you studied physics topics:

32. **How often did you discuss students' ideas about a new topic before studying it?**
○ Never
○ Rarely
○ Occasionally
○ Often
○ Always

33. **How often did you discover that you had misconceptions about the physics concepts that you studied?**
○ Never
○ Rarely
○ Occasionally
○ Often
○ Always

34. **How would you best characterize your physics course?**
A small number of topics in great depth ① ② ③ ④ ⑤ Many topics in little depth

Concerning tests, class discussion, and examples in your high school physics course:

35. **How much time did your teacher talk during each class, on average?**
○ Less than 5 minutes ○ 10 minutes ○ 40 minutes
○ 5 minutes ○ 20 minutes

36. **How much time did students talk during each class, on average?**
○ Less than 5 minutes ○ 10 minutes ○ 40 minutes
○ 5 minutes ○ 20 minutes

37. **How often were examples from the everyday world used?**
Never ① ② ③ ④ ⑤ Very often

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38. **How often did tests include questions that could be solved without math?**
○ Never
○ Rarely
○ Occasionally
○ Often
○ Always

39. **How often did tests include questions that related to your lab work?**
○ Never
○ Rarely
○ Occasionally
○ Often
○ Always

Rate these characteristics of your high school physics teacher:

40. **Knowledge of physics?**
Low ① ② ③ ④ ⑤ High

41. **Teaching ability?**
Low ① ② ③ ④ ⑤ High

42. **Friendliness?**
Not Friendly ① ② ③ ④ ⑤ Very Friendly

43. **Explained problems in several different ways?**
Never ① ② ③ ④ ⑤ Always

Concerning the science courses and standardized tests that you have taken:

44. **What was your highest level of mathematics in high school?**
○ Algebra I ○ Geometry ○ Calculus
○ Algebra II ○ Trigonometry

45. **What science courses did you take besides physics?**
○ Biology only ○ Biology and chemistry
○ Chemistry only

46. **What grade did you get in your last high school physics course?**
○ A ○ B ○ C ○ D ○ F

47. **What grade did you get in your last high school science class, other than physics?**
○ A ○ B ○ C ○ D ○ F

48. **What grade did you get in your last high school English course?**
○ A ○ B ○ C ○ D ○ F

49. **What grade did you get in your last high school math course?**
○ A ○ B ○ C ○ D ○ F

50. **What score did you get on your math aptitude SAT?**
○ Didn't take it ○ 200-300 ○ 500-600
○ 300-400 ○ 600-700
○ 400-500 ○ 700-800

51. **What score did you get on your verbal aptitude SAT?**
○ Didn't take it ○ 200-300 ○ 500-600
○ 300-400 ○ 600-700
○ 400-500 ○ 700-800

Concerning the effect background has on learning physics this semester:

52. **How much better will students who took physics in high school do in this course than those who did not take physics? Keep in mind that we are using a 100 point scale where an A = 95, a B = 85, a C = 75, etc.**
○ Less well
○ No difference in grade
○ 1 point better
○ 3 points better (example: the difference between a B- and B)
○ 5 points better (example: the difference between a B- and B+)
○ 10 points better (example: the difference between a B- and A-)
○ More than 10 points better

53. **For how long into this course does a high school physics background help students?**
○ Does not help at all ○ First 4 weeks
○ First 1 week ○ First 2 months
○ First 2 weeks ○ For the entire semester

Concerning your involvement and interest in science outside of regular school activities:

54. **Did you enter projects in the high school science fair?**
○ Never ○ Once ○ More than one year
○ No science fair

55. **What was the highest level of education of your male parent or guardian?**
○ Did not finish high school ○ Four years of college
○ High school ○ Graduate school
○ Some college

56. **What was the highest level of education of your female parent or guardian?**
○ Did not finish high school ○ Four years of college
○ High school ○ Graduate school
○ Some college

57. **What year are you in college?**
○ Freshman ○ Senior
○ Sophomore ○ Graduate student
○ Junior ○ Other

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