

TRANSITIONS

The Two High-School Pillars Supporting College Science

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Do students need chemistry in order to understand biology? Is biology the best foundation for beginning science students? How is the study of mathematics associated with the study of science? Whether the sequence of science courses has any cognitive relevance is a matter of dispute among science educators, especially given the emerging interdisciplinary underpinnings of traditional ideas in each field. For example, understanding chemical models requires some knowledge of the physics of electrostatics, and a solid foundation in lipid and protein chemistry can help explain the construction of cellular membranes (1–3). Meanwhile, the role of mathematics is considered to be less crucial to introductory biology coursework than to physics. One group, often referred to as the “Physics First” movement, promotes a reversal of the traditional biology-chemistry-physics high-school course sequence on the premise that key concepts from physics would better prepare students to study chemistry and even biology (4–6). To study this theory, we assumed that the benefits of high-school science preparation would extend into college (i.e., a student who has completed high-school physics may perform differently in a college chemistry class than a student who has not taken physics).

In the United States, high-school students can choose the number of years that they study each science subject [none, one year, or a second year, commonly Advanced Placement (AP)] and mathematics (i.e., Algebra II or lower, pre-calculus, calculus, or AP calculus). We analyzed the association between varying amounts of high-school biology, chemistry, physics, and mathematics preparation and performance in introductory college science. Although not an experimental design, this approach does offer the advantage of large participant

numbers, while approximating the impact of prior science learning on subsequent science performance. By analyzing the cross-disciplinary benefits of these subjects across high school and college, we sought to bring empirical evidence to a debate that is often fueled by rhetoric.

Sample, Instrument, and Analysis

We randomly selected 77 colleges and universities from a comprehensive list of roughly 1700 4-year institutions. To avoid overrepresenting small, but more numerous, liberal arts colleges, we used a representative stratified random sampling based on college size (<3000, 3000 to 10,000, and >10,000 students). In all, professors for 122 introductory biology, chemistry, and physics courses at 63 of these colleges and universities participated. Only science courses satisfying requirements for science majors in each discipline were surveyed. We excluded from our analysis students who did not attend a U.S. high school, graduate students, and those not in degree programs. Our total sample consisted of 8474 undergraduate students enrolled in one of the three introductory science courses.

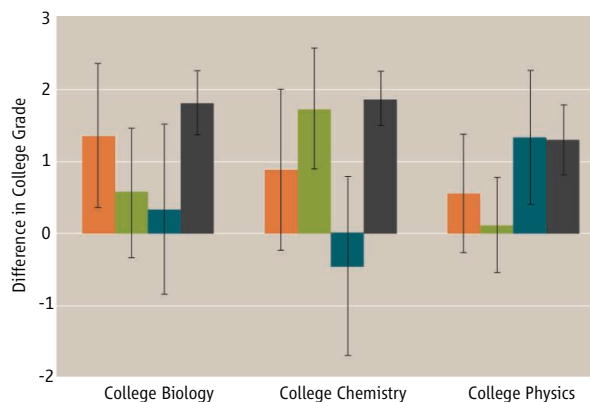
We designed three parallel surveys tailored to the disciplines of biology, chemistry, and physics, analogous to a previous pilot study of 2000 college physics students (7). We further informed our survey with a series of interviews with college students, high-school teachers, and college professors. We tested for response reliability in a separate analysis involving 113 college chemistry students who completed the chemistry survey twice, 2 weeks apart. The resulting survey included questions on how many high-school courses students had completed in each science subject and mathematics.

Ultimately, the surveys were administered to the sampled students while in class during the Fall semester. Professors

Out-of-discipline high-school science courses are not associated with better performance in introductory college biology, chemistry, or physics courses, but high-school math counts.

reported the final course grade of each student at the end of the term. We converted grades to scores using the following scale: A = 95, A– = 91, B+ = 88, B = 85, and so on. The mean grade was 80.41 (B–) with a standard deviation of 11.43.

We performed three parallel analyses, resulting in three separate yet comparable linear regression models (8). The sample sizes were $n = 2650$ for biology, $n = 3561$ for chemistry, and $n = 2263$ for physics. To account for differences among the college science courses (e.g., grading stringency), we used a college-effects model that assigned a variable to each college course (9). We chose variables to control for student background differences based on our earlier work (7, 10–12), which indicated that we should account for each student’s year in college. (Most biology and chemistry students were freshmen, but most physics students were sophomores or juniors). We also accounted for race and gender (tables S3 to S5) (7). Recognizing that the quality of teachers and resources available in a high school depends to some degree on the socioeconomic status of the community, we used



Effect of high-school science and mathematics on college science performance. The more high-school courses a student takes in a given subject, the better the student’s college grade in the same subject will be. The average grade-point increase per year of high-school biology (orange), chemistry (green), and physics (blue) is significant for a college course in the same subject but not for a college course in a different subject. Only high-school mathematics (gray) carries significant cross-subject benefit (e.g., students who take high-school calculus average better grades in college science than those who stop at pre-calculus). Grade points are based on a 100-point grade scale. Error bars represent 2 standard errors of the mean.

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parental education level and the mean education level of the community [retrieved from postal code data (10)]. Pre-college academic achievement of students was accounted for in the models by including self-reported standardized test scores. Using a concordance table, we converted ACT scores to SAT equivalents for this analysis (13). “Last high school English grade” and “last high school math grade,” along with “highest math course taken,” provided an estimate of educational achievement outside of science. Using these variables as a baseline model to account for demographic and educational differences, we accounted for the inclusion of the three high-school science predictors [years of biology instruction (ybi), years of chemistry instruction (yci), and years of physics instruction (ypi)]. The completion of high-school courses in each science discipline was entered as a continuous variable (0, 1, or 2 years). For the purposes of this discussion, we focused on the regression coefficients that may be interpreted as grade points on a 100-point final grade scale (see chart on page 457). We based our analytical approach on results from previous research relating to specific disciplines, block scheduling, and content coverage (10–12).

Results

Multiple linear regression analysis yielded three results: (i) an overall estimate of the outcome variable’s variation, (ii) estimated coefficients for predictor variables of the linear model, and (iii) each predictor variable’s associated level of statistical significance. The three multiple linear regression models in biology, chemistry, and physics accounted for variances of 32, 31, and 35%, respectively. We found that the three high-school science predictors (ybi, yci, and ypi) were only significant as predictors within their respective disciplines (effect size = 0.13 SD, $P < 0.01$) (see chart). No significant cross-disciplinary effect was found among the three science disciplines.

Years of mathematics instruction (ymi) was a significant predictor of performance across all college science subjects, including introductory college biology, a discipline not traditionally associated with strong mathematics preparation (effect size = 0.14 SD, $P < 0.001$) (see chart and tables S3 and S5).

Discussion

Our research examines correlations and does not offer the proof of causation that an experimental study could. However, the lack of significance in cross-disciplinary coursework supports the claim that cross-disciplinary



Math class. High-school math prepares students for college science.

coursework has a lesser role in preparation for performance than either intradisciplinary or calculus coursework. There may be unexamined variables that offer greater predictive power, such as interest level in a particular field or parental occupation.

Our surveys rely on accurate self-reporting of personal experiences from respondents, which presents an important limitation to consider. The accuracy of self-reports relies on context and relevance. Studies of students’ high-school course schedules have found self-reports to be reasonably accurate in comparison with transcript sources (14). A review of self-report studies has found that among college students, self-reports on academic backgrounds are also reasonably accurate (15). Surveying college science students during their college science classes about their high-school science experiences appears to meet the requirements of context and relevance. We found response reliability to be acceptable for the analysis we undertook in this study (16).

We also specifically investigated the ~10% of students in our sample who took high-school AP courses and then enrolled in the corresponding introductory college courses. We were concerned that these AP students in our sample might be biased toward underperformers. However, we found that the mean AP exam score for this group was 2.99, slightly higher (0.15 SD) than the overall mean of 2.81 reported by the College Board.

Our results have some application to the current debate concerning preparation for college science. We found, not surprisingly,

that high-school courses in biology, chemistry, and physics prepare students for college courses in the same field. We can also offer some empirical evidence to inform the debate on the reordering of high-school science courses. With regard to the “Physics First” movement, the lack of a relationship between the previous study of physics and later chemistry performance, or the previous study of chemistry and later biology performance, casts doubt on the impact of changing the traditional high-school science sequence. The two pillars supporting college science appear to be study in the same science subject and more advanced study of mathematics in high

school. Of course, this finding applies to introductory courses as they are currently taught in college, and the door remains open to develop and teach college courses that could make fuller use of student backgrounds built during high school in other science disciplines.

References and Notes

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Supporting Online Material

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