# Science Outcomes and Course Sequencing 

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## Overview

The history of science course sequencing started in 1893 when a committee determined which courses high schools should offer to prepare students for college. The science subcommittees recommended that chemistry immediately precede physics and that physics should be the last course in the sequence (Sheppard, 2003). The subcommittee explicitly noted that their recommended sequence was "plainly not the logical one" (National Education Association, 1893). However, they wanted to ensure students had as much math instruction as possible before encountering physics. The subcommittee logically preferred to place chemistry after physics since they viewed chemistry as the more abstract discipline. Biology was excluded from the sequence since the committee focused on the physical sciences.

In the early 1900s, the number of students enrolling in high school increased dramatically. Many of these students had no aspiration for college enrollment, which was the driving force behind many of the 1893 recommendations. Education institutions developed general science courses such as biology to meet the changing needs of their student population. The descriptive nature of the general biology courses led experts to recommend it sequenced before chemistry or physics (Hunter, 1934). However, modern biology classes incorporate elements of chemistry and physics into the curriculum. Likewise, chemistry's dependence on concepts such as energy, mass, and charge has led the American Association of Physics Teachers (AAPT) to adopt a physics-first attitude. The AAPT and other advocates suggest that physics should be the foundational ninth-grade science, followed by chemistry, then biology (AAPT, 2002; Ewald, 2005).

The Tennessee State Board policy requires students to earn three science credits in high school to graduate. The Knox County Schools district (KCS) does not mandate that the courses follow a specific sequence. Historically, most KCS schools chose to sequence courses as biology, followed by chemistry, and finally physics. However, there has been a recent shift in sequencing in some schools, with the most noticeable shifts occurring during the 2021-2022 school year (SY2122). Table 1 contains the number of students with transcript records in Biology I by grade level. The grey highlights correspond to the grade level with the most transcript records (by year). Readers should note a general decrease in the number of Biology I transcript records in ninth grade and an increase in eleventh-grade records. KCS schools are gradually shifting towards physics first followed by chemistry and then biology sequence.

Table 1: Number of Biology I Transcript Records in KCS by Year and Grade Transcript Grade

| School Year | 8 | 9 | 10 | 11 | 12 |
| :--- | :---: | :---: | :---: | :---: | :---: |
| $2016-2017$ | 82 | 2492 | 1244 | 526 | 60 |
| $2017-2018$ | 82 | 2365 | 1068 | 946 | 80 |
| $2018-2019$ | 94 | 2303 | 1057 | 889 | 115 |
| $2019-2020$ | 107 | 1568 | 1022 | 1034 | 114 |
| $2020-2021$ | 93 | 1323 | 1123 | 1257 | 185 |
| $2021-2022$ | 82 | 1261 | 1522 | 1707 | 218 |
| $2022-2023$ | 90 | 1040 | 1544 | 1592 | 199 |

The Knox County Schools (KCS) science department asked the Department of Research, Evaluation, and Assessment to investigate outcomes associated with science course sequencing. In September of 2023, district-level science facilitators asked REA to investigate two research questions related to science sequencing.

1. How do student outcomes on the state biology assessment (the sole high school science state test) vary by the grade level in which students take the course?
2. Do students earning science high school credits early (in accelerated eighth-grade courses) continue further into a science sequence than students earning their first science credit as ninth graders?

## Methodology: Research Question 1

REA chose logistic regression modeling to estimate the answer to the first research question. The regression analysis required an estimate of students' science ability. REA used the Tennessee Value-Added Assessment System (TVAAS) Biology I projected state percentiles as a proxy for longitudinal science ability. The TVAAS projection uses a student's state test in history (in all subject areas) to generate a predicted biology state percentile for a student. REA mapped the projections to SY2223 biology course schedules and state test results. We did not include demographic variables since controlling for previous state test performance serves the same purpose. The KCS science department requested REA separate the analysis by students taking honors biology from students taking college-prep (CP) biology. The final logistic regression model determines the probability of student i scoring proficient ("met expectations" or "exceeded expectations") on the biology state test after controlling for their projected state percentile and the grade level in which they took the biology exam.

$$
p\left(x_{i}\right)=\frac{1}{1+e^{-\left(\beta_{0}+\beta_{\text {Biology Pred. } \% \text { tile } i}+\beta_{\text {Grade Level } i}\right)}}
$$

Readers should note that the grade level in which a student enrolls in biology is heavily correlated with the school where the student is enrolled (see Appendix A). Therefore, REA cannot disentangle school-level effects from grade-level effects. We attempted to control for some school effects by using the biology projection (since the projection for students in grades 10-12 would include some diluted school effects). Readers should acknowledge that bias may impact the regression parameter estimates.

REA accomplished the logistic regression using R version 4.1.0 running on RStudio version 2023.09.01.

## Methodology: Research Question 2

REA accessed all transcript and science course schedules from two cohorts of students (the classes of 2022 and 2023) through SQL queries on ASPEN (the KCS student information system). REA linked biology state test records to schedules using unique state student identifiers. REA designed the analysis to follow students through a (possible) five-year high school course progression. We mapped district-level withdrawal data to the schedules to exclude students who left the district between eighth and twelfth grade. REA also excluded special education students enrolled in the alternative academic diploma program from the analysis.

## Results: Research Question 1

Figure 1 contains summary information for students enrolled in college-prep biology. The top panel shows the distribution of biology projections (the projected state percentile) by grade level. The bottom panel shows the percentage of students proficient on the state biology exam. 2,327 students took college-prep biology, had a biology projection, and had a valid biology test result (See Appendix A for details).


Figure 1: Summary Statistics for Biology CP

Table 2 contains the parameter estimates for the college-prep logistic regression. Table 3 contains the grade-level odds ratios. The results suggest taking college-prep biology in eleventh or twelfth grade increases the probability of a student scoring proficient on the state exam by an estimated factor of 2.17 and 2.75 , respectively. This difference is statistically different than the probability of a student scoring proficient as a ninth grader.

Table 2: Biology CP Logistic Regression Parameter Estimates

| Parameter | $\beta$ Estimate | Std. Error | z value | $\operatorname{Pr}(>\|\mathrm{z}\|)$ | Significance |
| :--- | :---: | :---: | :---: | :---: | :---: |
| Intercept | -3.49 | 0.20 | -17.53 | $<2 \mathrm{e}-16$ | $* * *$ |
| ACT Probability of Success | 6.37 | 0.26 | 24.51 | $<2 \mathrm{e}-16$ | $* * *$ |
| Grade Level $=10$ | 0.48 | 0.21 | 2.32 | 0.02 | $*$ |
| Grade Level $=11$ | 0.78 | 0.19 | 4.06 | 0.00 | $* * *$ |
| Grade Level $=12$ | 1.01 | 0.37 | 2.77 | 0.01 | $* *$ |
|  | Significance Codes: $0=* * *, 0.001=* *, 0.01=*, 0.05=$. |  |  |  |  |

Table 3: Biology CP Logistic Regression Grade Level Odds Ratios

| Parameter | Odds Ratio | $\operatorname{Pr}(>\|z\|)$ | Significance |
| :--- | :---: | :---: | :---: |
| Grade Level $=9$ (Baseline) | 1 | NA |  |
| Grade Level $=10$ | 1.61 | 0.02 | $*$ |
| Grade Level $=11$ | 2.17 | 0.00 | $* * *$ |
| Grade Level $=12$ | 2.75 | 0.01 | $* *$ |
| $\quad$ Significance Codes: $0={ }^{* * *}, 0.001={ }^{* *}, 0.01=*, 0.05=$. |  |  |  |

Figure 2 contains summary information for students enrolled in honors biology. The top panel shows the distribution of biology projections (the projected state percentile) by grade level. The bottom panel shows the percentage of students proficient on the state biology exam. 1,207 students took honors biology, had a biology projection, and had a valid biology test result (See Appendix A for details).


Figure 2: Summary Statistics for Honors Biology

Table 4 contains the parameter estimates for the honors logistic regression. Table 5 contains the gradelevel odds ratios. The results suggest taking honors biology in eleventh grade increases the probability of a student scoring proficient on the state exam by an estimated factor of 2.94 . This difference is statistically different than the probability of a student scoring proficient as a ninth grader.

Table 4: Honors Biology Logistic Regression Parameter Estimates

| Parameter | Estimate | Std. Error | z value | $\operatorname{Pr}(>\|\mathrm{z}\|)$ | Significance |
| :--- | :---: | :---: | :---: | :---: | :---: |
| Intercept | -2.78 | 0.29 | -9.69 | $<2 \mathrm{e}-16$ | $* * *$ |
| ACT Probability of Success | 6.07 | 0.39 | 15.67 | $<2 \mathrm{e}-16$ | $* * *$ |
| Grade Level $=10$ | 0.53 | 0.22 | 2.39 | 0.02 | $*$ |
| Grade Level $=11$ | 1.08 | 0.27 | 3.97 | 0.00 | $* * *$ |
| Grade Level $=12$ | 10.40 | 535.41 | 0.02 | 0.98 |  |
| Significance Codes: $0=* * *, 0.001=* *, 0.01=*, 0.05=$ |  |  |  |  |  |

Table 5: Honors Biology CP Logistic Regression Grade Level Odds Ratios

| Parameter | Odds Ratio | $\operatorname{Pr}(>\|z\|)$ | Significance |
| :--- | :---: | :---: | :---: |
| Grade Level $=9$ (Baseline) | 1 | NA |  |
| Grade Level $=10$ | 1.7 | 0.02 | $*$ |
| Grade Level $=11$ | 2.94 | 0.00 | $* * *$ |
| Grade Level $=12$ | 3.3 | 0.98 |  |
| Significance Codes: $0=* * *, 0.001=* *, 0.01=*, 0.05=$. |  |  |  |

## Results: Research Question 2

Table 6 shows summary data from the last two complete cohorts of KCS graduates (the classes of 2022 and 2023). Table 6 shows the mean, median, minimum, and maximum number of high school science credits earned by different groups of students (those taking high school biology as eighth graders, those taking high school physical science as eighth graders, and those taking general science as eighth graders). We remind readers the table will only include students continuously enrolled in KCS schools from eighth through twelfth grade. The median number of high school science credits earned was higher for students enrolled in a high school science course as an eighth grader. At least $50 \%$ of the students taking high school science as eighth graders earned more than the three science credits. The table in Appendix $B$ shows the number of credits earned by stanine.

Table 6: Number of Science Credits Earned by Student; Classes of 2022 and 2023
Number of Credits Earned Per Student

| 8th Grade Science Course | N Students | Mean | Median | Minimum | Maximum |
| :--- | :---: | :---: | :---: | :---: | :---: |
| High School Biology | 168 | 5.55 | 5 | 3 | 14 |
| High School Physical Science | 1593 | 4.81 | 4 | 1 | 14 |
| 8th Grade General Science | 4607 | 3.32 | 3 | 0 | 10 |

Table 7 shows the number of students who were not enrolled/scheduled in a science class in the twelfth grade. REA could include an additional cohort of students (the class of 2024) since SY2324 schedules are in ASPEN. Appendix C contains a list of science courses in which schools scheduled seniors.

|  | Graduation Year |  |  |
| :--- | :---: | :---: | :---: |
| 8th Grade Science Course | 2022 | 2023 | 2024 |
| High School Biology | 35 | 51 | 38 |
| High School Physical Science | 483 | 493 | 531 |
| 8th Grade General Science | 1472 | 1466 | 1561 |

## Conclusions

KCS should consider multiple arguments and outcomes when deciding on science course sequencing. The APPT has adopted a "physics first" attitude since the early 2000s. They argue that the content of modern science courses builds logically from physics to chemistry to biology. However, the concerns raised by science experts in 1893 regarding math prerequisites for physics are still valid. Recent research suggests that there are still lingering questions about how to align science and math curricula to support a "physics first, biology last" sequence (Larkin, 2016). KCS should ensure that the ultimate decision on science course sequencing involves input from KCS math specialists.

Decision makers may interpret REA's analysis as supporting a "physics first, biology last" sequence. REA's findings suggest students taking biology later perform better on the state biology exam. This may be nontrivial since biology is the only state-tested science course included in state accountability systems. However, the strength of the analysis is questionable for a few reasons. Firstly, REA cannot disentangle school-level effects from grade-level estimates. We cannot rule out that the statistically significant variation in test scores is a function of the school a student attends instead of the grade level in which they take biology. It is also possible that impacts from the SY1920 COVID-19 shutdown may fundamentally impact the relationships between the covariates.

REA's findings make sense since similar studies have found that older high school students perform better on state tests (Sheppard, 2003). Older students are more mature and have access to more extensive background knowledge. It seems likely that any science course placed later in the progression would have better test results than if it was sequenced earlier. There may be unintended consequences on other science outcomes (such as pass rates on Advanced Placement or Dual Credit science exams) by changing the sequence to "physics first, biology last."

Finally, KCS's science acceleration policy appears to function as intended. Students taking high school science as eighth graders generally take more science courses than students who don't. KCS’s science acceleration allows students to advance farther in the science sequence.

## References

American Association of Physics Teachers. (2002). AAPT statement on physics first. AAPT Announcer, 32(3), 11.

Ewald, G., Hickman, J. B., Hickman, P., \& Myers, F. (2005). Physics first: The right-side-up science sequence. The Physics Teacher, 43(5), 319-320.

Hunter, G. W. (1934). Science Teaching: At Junior and Senior High School Levels. New York: American Book Company.

Larkin, D. B. (2016). Putting physics first: Three case studies of high school science department and course sequence reorganization. School Science and Mathematics, 116(4), 225-235.

National Education Association. (1893). Report of the committee on secondary school studies. Washington, D.C.: Government Printing Office.

Sheppard, K., \& Robbins, D. M. (2003). Physics Last: A Historical Study of the Development of the US High School Science Sequence.

## Appendix A: Student Counts (by School and Grade Level) Included in the Regression Analysis

| School | \# of Students in Biology I Regressions by Grade and School |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | College Prep |  |  |  | Honors |  |  |  |
|  | 9 | 10 | 11 | 12 | 9 | 10 | 11 | 12 |
| Austin-East High School | 103 | 23 | 7 | 0 | 20 | 1 | 0 | 0 |
| Bearden High School | 1 | 13 | 177 | 6 | 137 | 3 | 50 | 0 |
| Career Magnet Academy | 77 | 7 | 2 | 0 | 0 | 0 | 0 | 0 |
| Carter High School | 0 | 3 | 78 | 8 | 0 | 18 | 6 | 0 |
| Central High School | 187 | 26 | 20 | 1 | 50 | 41 | 0 | 0 |
| Farragut High School | 0 | 1 | 136 | 11 | 88 | 4 | 23 | 0 |
| Fulton High School | 2 | 158 | 8 | 3 | 16 | 32 | 1 | 0 |
| Gibbs High School | 0 | 33 | 110 | 12 | 14 | 31 | 34 | 0 |
| Halls High School | 6 | 88 | 16 | 1 | 54 | 16 | 0 | 0 |
| Hardin Valley Academy | 1 | 96 | 131 | 11 | 0 | 122 | 25 | 1 |
| Karns High School | 1 | 223 | 48 | 9 | 1 | 76 | 15 | 0 |
| Kcs Virtual High School | 1 | 2 | 22 | 0 | 4 | 4 | 6 | 0 |
| Knox Adaptive Education Center | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| L \& N STEM Academy | 0 | 9 | 31 | 0 | 0 | 45 | 17 | 0 |
| Powell High School | 2 | 7 | 158 | 17 | 0 | 47 | 16 | 0 |
| Richard Yoakley Alt | 6 | 4 | 4 | 0 | 0 | 0 | 0 | 0 |
| South Doyle-High School | 0 | 3 | 133 | 2 | 1 | 33 | 14 | 0 |
| West High School | 3 | 73 | 3 | 0 | 72 | 69 | 0 | 0 |

## Appendix B: Number of High School Science Credits Earned by Eighth Grade Science Course

| 8th Grade Science Course | N <br> Students | Number of Credits Earned by Stanine |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 10th <br> \%tile | 20th <br> \%tile | 30th <br> \%tile | 40th <br> \%tile | 50th <br> \%tile | 60th <br> \%tile | 70th \%tile | 80th <br> \%tile | 90th <br> \%tile |
| High School Biology | 168 | 3 | 4 | 4 | 4.8 | 5 | 5 | 6 | 7 | 9 |
| High School Physical Science | 1593 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 6 | 7 |
| 8th Grade General Science | 4607 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 |

## Appendix C: Science Courses Taken in Twelfth Grade Year (By Science Course Taken in Eighth Grade)

| Senior Year Science Course | High School Biology |  |  | High School Physical Science |  |  | 8th Grade General Science |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 2022 | 2023 | 2024 | 2022 | 2023 | 2024 | 2022 | 2023 | 2024 |
| AGRISCIENCE |  |  |  |  |  | 3 |  |  | 17 |
| ANAT/PHYSIO |  |  | 1 | 32 | 25 | 20 | 143 | 117 | 166 |
| AP BIOLOGY | 1 | 1 | 5 | 33 | 19 | 23 | 23 | 14 | 10 |
| AP CHEMISTRY | 1 | 3 | 2 | 12 | 14 | 7 | 12 | 8 | 3 |
| AP ENV SCIENCE | 7 | 9 | 12 | 30 | 31 | 34 | 30 | 24 | 36 |
| AP PHYSICS C MECHANICS | 4 | 3 | 10 | 26 | 11 | 27 | 4 | 2 | 4 |
| AP PHYSICS 1 | 4 | 2 | 4 | 6 | 29 | 19 | 6 | 9 | 9 |
| AP PHYSICS 2 | 2 | 6 | 4 |  | 2 | 4 | 2 | 3 |  |
| AP PHYSICS C EM | 3 | 1 | 7 | 10 |  | 6 | 2 |  |  |
| ASTRONOMY | 7 | 3 |  | 28 | 24 | 20 | 41 | 44 | 39 |
| BIOLOGY 1 A |  |  |  |  |  |  | 1 |  | 1 |
| BIOLOGY 1 B |  |  |  |  |  |  | 4 |  | 6 |
| BIOLOGY 1 CP |  |  |  | 4 | 7 | 1 | 118 | 114 | 158 |
| BIOLOGY 2 |  |  |  | 1 | 1 | 1 | 22 | 14 | 11 |
| BOTANY ZOOLOGY | 4 | 6 | 8 | 7 | 6 | 32 | 19 | 30 | 34 |
| CHEMISTRY 1 |  | 1 |  |  | 4 | 2 | 186 | 185 | 142 |
| DE BIOLOGY I |  |  | 1 | 4 | 21 | 23 | 7 | 14 | 13 |
| DE BIOLOGY II |  |  |  |  | 14 |  | 1 | 9 |  |
| DE GEN CHEMISTRY I |  |  |  | 3 | 2 | 3 |  | 1 | 1 |
| DE GEN CHEMISTRY II |  |  |  | 1 | 1 | 1 |  |  |  |
| DE HUMAN ANATOMY / PHYSIOLOGY I | 6 | 7 | 7 | 8 | 11 | 17 | 9 | 13 | 12 |
| DE HUMAN ANATOMY / PHYSIOLOGY II |  | 1 |  |  |  |  |  | 2 |  |
| DE NON-CALC BASED PHYSICS I |  |  |  | 1 | 1 |  |  |  |  |
| DE NON-CALC BASED PHYSICS II |  |  |  | 1 |  |  |  |  |  |
| DE SCIENCE | 6 | 3 | 14 | 5 | 25 | 32 | 2 | 11 | 12 |
| EARTH AND SPACE SCIENCE |  |  |  | 2 | 2 | 1 | 16 | 20 | 16 |
| ECOLOGY CP |  |  |  | 4 | 7 |  | 62 | 48 | 21 |
| ENVIRONMENTAL SCIENCE |  |  |  | 2 | 3 | 8 | 67 | 48 | 73 |
| GEOLOGY |  |  |  | 5 | 2 | 2 | 29 | 20 | 22 |
| HON BIOLOGY |  |  |  | 2 | 1 |  |  | 1 | 1 |
| HON BIOLOGY 2 | 1 | 1 | 5 | 35 | 19 | 24 | 26 | 16 | 12 |
| HON CHEMISTRY |  |  |  | 1 |  | 1 | 1 |  | 1 |
| HON CHEMISTRY 2 | 1 | 6 | 2 | 15 | 16 | 7 | 15 | 12 | 5 |
| HON ENVIRONMENTAL SCIENCE | 2 | 1 | 1 | 1 | 1 | 1 | 6 | 3 | 4 |
| HON HUMAN ANATOMY \& PHYSIOLOGY | 3 | 5 | 3 | 14 | 19 | 9 | 22 | 25 | 29 |
| HON INTRO ORGNC/BIOCHEM | 4 | 3 | 4 | 5 | 3 | 5 | 2 | 3 | 6 |
| HON PHYSICS |  |  |  | 14 | 22 | 13 | 10 | 7 | 14 |
| HON SCIENTIFIC RESEARCH | 3 |  |  | 5 | 2 | 5 | 3 |  | 5 |
| IB BIOLOGY HL YR 1 |  |  |  |  |  |  |  | 1 |  |
| IB BIOLOGY HL YR 2 |  |  |  | 10 | 6 | 11 | 9 | 3 | 3 |
| IB CHEMISTRY HL YR 1 |  |  |  |  | 2 |  |  |  |  |
| IB CHEMISTRY HL YR 2 |  |  |  | 14 | 6 | 11 | 1 | 1 | 1 |
| IB ESS SL YR 2 |  |  |  | 10 | 11 | 17 | 9 | 6 | 5 |
| IB PHYSICS HL YR 2 |  |  |  | 9 | 10 | 11 | 4 | 3 | 2 |
| MARINE ECOLOGY |  |  |  | 13 | 10 | 17 | 19 | 27 | 49 |
| MICROBIOLOGY |  |  |  | 11 | 13 | 4 | 12 | 8 | 4 |
| NIC PRINCIPLES OF AGRISCIENCE |  |  |  |  |  |  | 8 |  |  |
| PHYSICAL SCIENCE CP |  | 1 |  | 1 |  |  | 39 | 57 | 23 |
| PHYSICS | 1 |  |  | 10 | 13 | 3 | 22 | 25 | 25 |
| PRIN OF PLANT SCI AND HYDROCULTURE |  |  |  |  |  |  | 5 |  |  |
| SCIENTIFIC MODELING |  |  |  | 5 |  |  | 7 |  |  |
| SCIENTIFIC RESEARCH |  |  |  |  | 11 | 29 |  | 43 | 32 |
| WILDLIFE PRINCIPLES |  | 6 | 4 | 18 | 5 | 7 | 48 | 17 | 20 |

