JUNE 2021

Advanced Placement® Calculus and Physics and TIMSS Advanced 2015: Performance Report

Christopher C. Lazzaro, Ph.D.—Director, Science Education, College Board

Tom Loveless, Ph.D.—Nonresident Senior Fellow, Brookings Institution

Stephen Sireci, Ph.D.—Professor, Psychometrics, University of Massachusetts Amherst

David C. Webb, Ph.D.—Associate Professor, Math Education, University of Colorado Boulder

Contents

Tables and Figures

Executive Summary

This study examined outcomes for AP® Calculus and AP Physics students on the 2015 Trends in International Math and Science Study (TIMSS) relative to other participating countries and other advanced math and science students in the United States. Compared to other countries in the study, AP Calculus BC and AP Physics C: EM students outperformed all participating education systems and other AP groups. Data also show that higher percentages of AP Calculus and Physics students reached international benchmarks, earned higher average content domain scores, and spent more time engaged in math and science than other advanced math and science students in the U.S. who did not take AP.

Introduction

Education scholars from several nations met in Hamburg, Germany, in June 1959 to discuss "an international study of intellectual functioning."[1] No scientifically rigorous international assessment had ever been attempted before. Many doubted that student learning could be assessed accurately across countries with vastly different languages, cultures, and educational systems. The group of researchers, which was later formally named the International Association for the Evaluation of Educational Achievement (IEA), planned a pilot study to determine whether an international project was even feasible. The pilot study was completed in 1960. It convinced the IEA's founders, who included Benjamin Bloom of the University of Chicago and Robert L. Thorndike of Columbia University, that an international assessment was not only feasible, but could also produce meaningful comparisons among participating nations.

Math was selected as the first school subject for assessment. The first international math study (FIMS) was conducted in 1964 in 12 countries. The final sample consisted of 132,775 students and 13,364 teachers from 5,348 schools. Students were assessed at two points in schooling—age 13 and the final year of secondary school (i.e., senior year in American high schools). This being a time of limited computing and communication facilities, it took three years to collect, to process, and to analyze the data (Trosten 1967).

The results were released in a two-volume report published in 1967 (Husen 1967). The United States' performance was disappointing. For 13-year-olds, the U.S. ranked next to last, in 11th place. American researchers had already anticipated low scores. The Washington Post headline of March 12, 1967 read, "Poor U.S. Math Showing Didn't Surprise Experts," noting, "The experts assert that teachers here are not as well trained, and that neither American students nor the society at large places as much value on mathematics achievement as do many countries abroad." The New York Times bluntly declared, "The U.S. Gets Low Marks in Math."

FIMS was followed by the Second International Math Study (SIMS) in 1980-81 and the Third International Math and Science Study (TIMSS) in 1995. Having decided to conduct TIMSS every four years, the project later kept the TIMSS acronym but changed what it stood for, becoming the Trends in International Mathematics and Science Study. TIMSS 1995 focused on students in two elementary school grades (third and fourth) and two in middle school (seventh and eighth grades). TIMSS was repeated in eighth grade in 1999 (called TIMSS-R). Beginning in 2003, all subsequent TIMSS assessments were administered in fourth and eighth grades.

Another 1995 innovation was the addition of TIMSS Advanced, an assessment targeting students in their final year of secondary school who are taking advanced math and science

1. This idea was expressed in a 1958 proposal to the UNESCO Institute for Education.

courses. Nineteen countries took part. TIMSS Advanced was administered again in 2008 and 2015, with 10 countries participating in 2008 and 9 countries in 2015 (see Table 1).

Table 1: TIMSS Advanced Participating Countries

Education System	1995 Last-year Secondary School	2008 Last-year Secondary School	2015 Last-year Secondary School
Armenia		●	
Australia	●		
Austria	●		
Canada	●		
Cyprus	●		
Czech Republic	●		
Denmark	●		
France	●		●
Germany	●		
Greece	●		
Iran, Islamic Republic of		●	
Israel	●		
Italy	●	●	●
Latvia[1]	●		
Lebanon		●	●
Lithuania[2]	●		
Netherlands		●	
Norway[1]	●	●	●
Philippines		●	
Portugal			●
Russian Federation	●	●	●
Slovenia	●	●	●
Sweden	●	●	●
Switzerland	●		
United States	●		●

● = Indicates participation in particular assessment with results reported or forthcoming.

1 Administered physics but not advanced mathematics in 1995.

2 Administered advanced mathematics but not physics in 1995.

Note: OECD member countries are bolded.

Source: International Association for the Evaluation of Educational Achievement (IEA), Trends in International Mathematics and Science Study (TIMSS); this comes from the website, https://nces.ed.gov/timss/countries_advanced.asp

TIMSS Advanced 2015

The 2015 TIMSS Advanced test assessed student knowledge in advanced mathematics and physics. In terms of content, the physics test covers mechanics and thermodynamics, electricity and magnetism, and wave phenomena and atomic/nuclear physics. The advanced mathematics assessment covers algebra, geometry, and calculus. In both subjects, three cognitive domains (knowing, applying, and reasoning) specify thinking processes that students employ to address the items.

Each participating country determines student eligibility for TIMSS Advanced. In general, students must be in the final year of secondary education and enrolled in the math or physics course serving each nation’s most advanced students, typically those intending to study mathematics or science in college. An individual student may belong to the advanced math target population, the physics target population, or both. U.S. students who belong to both are randomly assigned either to the math or physics assessment, ensuring that each student participating on TIMSS Advanced only takes one test. Matrix sampling is used for both assessments, with six booklets in advanced math and six booklets in physics. Each student completes a single booklet. Booklets are distributed among the students in each sampled class according to a predetermined order, so that approximately equal proportions of students respond to each booklet.

Scores are placed on achievement scales so that changes in achievement can be estimated over time. The TIMSS Advanced scales are based on the 1995 assessments, with the scale centerpoint set at 500, equal to the international average across all participating countries in 1995, and one standard deviation equal to 100 scale points. Including common items on 1995, 2008, and 2015 administrations of TIMSS Advanced has allowed the linking of scores over the entire 20-year period so that countries can calculate progress in advanced math and physics performance (more on TIMSS methods can be found in this report’s methodology section).

In addition to the assessments, TIMSS Advanced collects data through questionnaires distributed to students, teachers, and school principals. The questionnaires gather information on factors that may affect student learning. These factors include:

- Students’ academic preparation for advanced math and physics
- Students’ educational aspirations
- Students’ attitudes toward math and science
- Teachers’ education and training

- Teachers' instructional strategies
- Use of technology by students and teachers

Our Study

The questionnaire topics listed above are interesting because they may be related to student achievement. But that does not mean TIMSS data allow for rigorous tests of causality. Students are not randomly assigned to advanced math and physics courses. Moreover, even though the selected samples are designed to be representative of the advanced students from which they are drawn, cross-sectional data only allow for estimates of phenomena taking place at a single point in time. Thus, the study below is primarily descriptive. We seek to explore how advanced students in the U.S. performed on the TIMSS Advanced test in 2015 and by closely examining questionnaire data from students, teachers, and school administrators, to describe the contexts in which teaching and learning occurred. These are the nation's most advanced students in math and science. We hope that our report allows readers to know them a little better.

Our study contains an element that previous studies of U.S. performance on TIMSS Advanced have not been able to pursue, the ability to disaggregate data by Advanced Placement® (AP) Program status. The AP Program provides students the opportunity to take college-level course work while in high school. AP offers two courses in calculus—Calculus AB and Calculus BC—and four courses in physics—Physics 1, Physics 2, Physics C: Electricity and Magnetism, and Physics C: Mechanics. College and university faculty review AP courses to ensure alignment with college-level expectations (full course descriptions can be found online[2]). AP courses conclude with a culminating exam. Many colleges and universities accept a successful score (typically 3 or above on a 5-point scale) for credit or advanced placement.[3]

The study is guided by two key questions:

1. How do AP and non-AP students compare, both to each other and to students internationally, in performance on TIMSS Advanced? This question is tackled in section 3.
2. What are some of the contextual factors that differentiate the learning experience of AP and non-AP students? The analysis is presented in section 4.

We organize the contextual factors by themes: student preparation, technology, teachers and teaching, and student attitudes and aspirations.

2. https://apcentral.collegeboard.org/courses

3. *AP Program Guide 2016-17* (College Board, 2016).

Student Preparation

Education reform movements spurred by Sputnik in the 1950s and *A Nation at Risk* in the 1980s urged American students to take more challenging courses, particularly in math and science. Several studies have documented the correlation of advanced course work in high school with high achievement and later success in college.[4] Leow et al. (2004) used propensity scoring to investigate the effect of advanced course taking on performance on the TIMSS 1995 assessment. The authors found that taking advanced math and science courses significantly associated with higher achievement compared to non-advanced course taking.

Less research has been conducted on how students are prepared for taking advanced math and science in high school and the specific pathways advanced students travel while studying the two subjects. Advanced science has historically comprised courses in biology, chemistry, and physics, but local customs and policies dictate the sequence of offerings. Although the math sequence has always been more clearly defined (Algebra I, Geometry, Algebra II, and Calculus), enrollment in the first steps of the continuum have recently been in flux. Enrollment in advanced math courses (Algebra I or higher) in eighth grade nearly tripled from 1990 to 2011, going from 16% to 47%.[5] Unfortunately, recent studies of student transcripts reveal an extremely leaky pipeline. A California study, for example, found that 57% of students took Algebra I for the first time in eighth grade, but three years later only 15.3% had passed Algebra I, Geometry, and Algebra II in grades 8, 9, and 10, respectively.[6]

TIMSS Advanced students were asked to report the grade in which they took math and science courses, beginning with eighth grade. We analyze those responses to find out who took which courses and when they took them, mapping the curricular pathways students traversed to arrive, finally, as high school seniors, in advanced calculus and physics classrooms.

Technology

Advocates argue that greater use of technology will improve curriculum and instruction, leading to increased student achievement and enthusiasm for academic subjects. Recent reports indicate that many schools are not able to make use of the benefits of technology due to a lack of resources, expertise, and access to reliable information (NEA 2008). Lytle (2011) reports that K–12 teachers who implemented technology in their classrooms believe that it positively affected their students' achievement and productivity. While schools and

4. Adelman (1999). Answers in the Toolbox: Academic Intensity, Attendance Patterns, and Bachelor's Degree Attainment; Leow et al. (2004); Long, Conger, and Lataola (2012). Effects of high school course-taking on Secondary and PostSecondary Success, American Educational Research Journal, 49 (2), pp. 285-322.

5. NAEP data, as reported in Loveless (2013), "Advanced Math in Eighth Grade," 2013 Brown Center Report on American Education.

6. Finkelstein et al. (2012), "College Bound in Middle School and High School?" WestEd.

districts have begun infusing technology into the curriculum, about 27% (according to a study by CompTIA 2011) of educators still experience budgetary constraints and other obstacles that hinder efforts.

Technology permeates every aspect of students' lives, perhaps to a larger extent outside of school than within. We examine data from the TIMSS Advanced questionnaires for both teachers and students to explore the role of technology in the study of math and science.

Teachers and Teaching

Shortages in the pool of qualified STEM teachers have been a policy concern for a long time in the U.S. Research has shown that teacher experience is positively correlated with student achievement, but the relationship weakens after five years of experience teaching.[7] A policy concern that arose in Norway after the release of 2008 TIMSS Advanced was the percentage of teachers who were approaching retirement age.[8] All over the world, advanced math and science courses tend to be staffed by schools' most experienced teachers, so their retirements represent a large loss of human capital.

TIMSS questionnaires ask teachers about their age, level of education, and teaching experience. They also ask about instructional strategies and confidence in the ability to engage in several teaching practices. Because pedagogical reform has been the focus of math and science policy efforts in recent years, an analysis of teachers' responses will be timely.

Student Attitudes and Aspirations

Adolescents' aspirations and attitudes influence school achievement. A longitudinal study by Beal and Crocket (2010) on 317 adolescents investigated future aspirations, current activities, and educational attainment (see also, Gregory and Weinstein 2004). Regression analyses revealed that adolescent career aspirations ("What kind of work would you like to do?") predicted later educational attainment. Adolescents with professional work aspirations were more likely to attain higher levels of education later in life.

Several studies also show that students who like math and science tend to do well in them.[9] It makes sense that students who enjoy particular school subjects and envision them as part of their future careers would also be high achievers in those subjects. That said, the direction of causality, which comes first, attitudes or achievement, is ambiguous. Two

7. Rivkin, et al., 2001. Also see Jonah E. Rockoff (2004), "The Impact of Teachers on Student Achievement: Evidence from Panel Data" American Economics Association Papers and Proceedings, May 2004, 247–252.

8. Grønmo, L.S., Onstad, T., Pedersen, I.F., Lie, S., Angell, C., & Rohatgi, A. (2009). Mathematics and physics in upper secondary school. One step back. Abridged report presenting main results from TIMSS Advanced 2008 in Norway, Department of Teacher Education and School Development, University of Oslo.

9. Kusum Singh, Monique Granville, Sandra Dika (2002). "Mathematics and science Achievement: Effects of Motivation, Interest, and Academic Engagement, The Journal of Educational Research, vol. 95, no. 6, 323–332.

patterns from international assessments add to the ambiguity.[10] On both TIMSS and the Programme for International Student Assessment (PISA), the relationship between attitudes and achievement at the national level tends to be negative; that is, higher scoring countries in math and science have higher percentages of students saying they don't like the subjects—and vice versa. Students in lower scoring countries regard math and science much more positively.

Another observed pattern is that attitudes toward subjects are negatively correlated with age. Older K–12 students view subjects more negatively than younger students. The students in TIMSS Advanced are both high achievers and in the final year of high school. We examine responses to student questionnaires that reveal how America's best students in mathematics and science view both subjects and their educational and career aspirations for the future.

Methodology

Introduction

In this section, we present the methodology used to estimate achievement on TIMSS Advanced for particular subgroups and the analysis of the questionnaire data. These subgroups are specifically defined in this report to identify students who have taken an AP Exam and students who havenot participated in an AP Calculus or AP Physics course. This section will also outline the sampling design used in the U.S. for TIMSS Advanced 2015 and explain how the TIMSS coverage index is calculated for each participating country.

Sample Design for the U.S. in TIMSS Advanced 2015

The purpose of the TIMSS Advanced assessment is, "*to provide valid and reliable measurement of trends in student achievement in countries around the world*." In the United States, a nationally representative target sample was designed with input from the National Research Coordinator, the College Board, sampling staff from the IEA Hamburg, and Statistics Canada. This sample explicitly included students in AP Physics and AP Calculus courses, as well as students in other advanced math and physics programs (e.g., International Baccalaureate, dual-enrollment, etc.). In addition, the sampling frame was also expected to, "identify the programs, tracks, or courses that correspond to the international target population; create a sampling frame by listing all schools in the population that have classes with advanced mathematics and/or physics students in the target grade; determine national population coverage and exclusions, in accordance with the TIMSS Advanced international guidelines; work with Statistics Canada to develop a national sampling plan and identify suitable stratification variables, ensuring that these variables are present and correct for all schools; contact all sampled schools and secure their participation; keep track

10. Ina Mullis, Michael Martin, and Tom Loveless, (2016). *20 Years of Trends on TIMSS*.

of school participation and the use of replacement schools; and conduct all within-school sampling of classes" (LaRoche and Foy 2016, 2). It must be noted that the U.S. did not meet the sampling requirements on TIMSS Advanced 2015. A complete outline of the TIMSS Advanced international guidelines for sampling can be found in the *Methods and Procedures in TIMSS Advanced 2015* (2016).

Courses Included in Advanced Mathematics and Physics

While the TIMSS Advanced 2015 Assessment Framework outlines the content for the courses that define the target population of students, each country chose the courses to be included in the sample that they felt most closely matched this content. Often, these were the most advanced mathematics and physics courses each country had to offer. For mathematics in United States, the courses included, "students in the 12th grade who have taken an advanced mathematics course (AP, IB, or another advanced mathematics course specific to their state/district), in grade 12 or in a prior grade" (LaRoche and Foy 2016, 4). For physics in the United States, the courses included, "students in the 12th grade who have taken an advanced [physics] course (AP, IB, or another advanced physics course specific to their state/district), in grade 12 or in a prior grade" (LaRoche and Foy 2016, 4). For more details on U.S. sampling, see https://nces.ed.gov/timss/timss15technotes_sampling.asp.

TIMSS Advanced Coverage Indices

The TIMSS Advanced coverage index for math and physics is a measure of the "school-leaving age cohort taking advanced mathematics and physics courses" in each country (LaRoche and Foy 2016, 5). These indexes identify the "overall sampling coverage" for each country's population and represent the total percentage of the corresponding age cohort that would be considered "eligible" for TIMSS Advanced 2015 in each country. As outlined in the Methods and Procedures in TIMSS Advanced 2015, the TIMSS Advanced coverage indexes are calculated as follows:

$$TIMSS\ Advanced\ Math\ Coverage\ Index = \frac{\substack{Estimated\ total\ number\ of\ students\ in \\ the\ advanced\ mathematics\ population}}{\substack{Total\ national\ population\ in \\ the\ corresponding\ age\ cohort}} \times 100\%$$

$$TIMSS\ Advanced\ Physics\ Coverage\ Index = \frac{\substack{Estimated\ total\ number\ of\ students\ in \\ the\ advanced\ Physics\ population}}{\substack{Total\ national\ population\ in \\ the\ corresponding\ age\ cohort}} \times 100\%$$

Table 2 shows the calculated coverage indexes for the United States in both Advanced Mathematics and Advanced Physics.

Table 2: U.S. Coverage Index

United States	Years of Formal Schooling	Age Cohort Corresponding to the Final Year of Secondary School	Estimated Size of the Population of Students in the Final Year of Secondary School Taking Advanced Math/Physics	Size of the Age Cohort Corresponding to the TIMSS Advanced Population Based on National Census Figures	TIMSS Advanced Coverage Indices – the Percentage of the Entire Corresponding Age Cohort Covered by TIMSS Advanced Target Population
Math	12	18	473,405	4,168,000	11.4%
Physics	12	18	199,944	4,168,000	4.8%

Source: Adapted from LaRoche & Foy, 2016, p.6 & 7.

Operationally Defining the Advanced Placement Groups

For the purposes of this report, AP student groups were defined using data obtained from College Board about students who took specific AP Exams during 2015 and TIMSS Advanced 2015 data from the National Center for Educational Statistics. For TIMSS Advanced Math, we identified U.S. students who participated in TIMSS Advanced Math and who also took the AP Calculus AB Exam or the AP Calculus BC Exam (no students took both exams). These students were categorized as “AP students.” All other TIMSS Advanced students were categorized as “non-AP students.”

In analyzing the group of non-AP students, we found that 697 of these students who did not take an AP Exam in 2015[11] self-reported that they had taken or were currently enrolled in an AP Calculus AB course, and that 230 of these students self-reported that they had taken or were currently enrolled in an AP Calculus BC course (126 students self-reported they took both AB and BC courses). These students were deleted from the non-AP group. Thus, the final groups for this report’s analyses were defined as:

- *AP Calculus AB Students*: Students who took the AP Calculus AB Exam in 2015 who also took the TIMSS Advanced Mathematics assessment in 2015
- *AP Calculus BC Students*: Students who took the AP Calculus BC Exam in 2015 who also took the TIMSS Advanced Mathematics assessment in 2015
- *Non-AP Students*: Students who did not take the AP Calculus AB or BC Exams in 2015, AND who did not self-report ever taking either of the Calculus AB or BC courses, who also took the TIMSS Advanced Math exam in 2015

11. There were initially 1,454 students in the non-AP Calculus group.

For TIMSS Advanced Physics, we identified U.S. students who participated in TIMSS Advanced Physics and who also took the AP Physics 1, AP Physics 2, AP Physics C: Electricity and Magnetism (AP Physics C:EM), or the AP Physics C Mechanics (AP Physics C:M) exams. We initially created separate AP groups based on the AP Exams taken, but there were a small number of students who took more than one of these exams. Therefore, we decided to form the AP groups based on the "highest" AP Physics Exam taken, with Physics 1 being the lowest in the hierarchy, and Physics C:EM being the highest. Given that the Physics 2 group was only 55 students, we omitted them from the analysis. Students who met these criteria were categorized as "AP students." All other TIMSS Advanced students were categorized as "non-AP students."

Similar to the TIMSS Advanced 2015 Advanced Mathematics data, there were many students in the TIMSS Advanced Physics non-AP group who responded they had taken or were currently enrolled in an AP Physics course (954 students[12]). These students were omitted from the non-AP group. Thus, the final groups were defined as:

- *AP Physics 1 Students:* Students who took the AP Physics 1 Exam (or students who took both AP Physics 1 and Physics 2 Exams) in 2015 who also took the TIMSS Advanced Physics exam in 2015
- *AP Physics C:M Students:* Students who took the AP Physics C:M Exam in 2015 who did not take the AP Physics C:EM Exam, and who also took the TIMSS Advanced Physics exam in 2015
- *AP Physics C:EM Students:* Students who took the AP Physics C:EM Exam in 2015, who also took the TIMSS Advanced Physics exam in 2015
- *Non-AP Students:* Students who didn't take an AP Physics Exam in 2015, AND who didn't self-report ever taking a physics course, who also took the TIMSS Advanced Physics exam in 2015

In Table 3 we report the sample sizes for these groups for physics and mathematics. It should be noted that for the analyses reported in the body of this report, we applied the TIMSS Advanced student *house weights*, so that the results would reflect population inferences, rather than just characteristics of the samples.

[12] There were initially 1,692 students in the non-AP Physics group.

Table 3: Calculus and Physics: Analytical Group Sample Sizes

Group		N	Percentage
AP Calculus AB		1,151	52.3
AP Calculus BC		398	18.1
Non-AP		653	29.7
	Total	**2,202**	**100.0**
AP Physics 1		713	36.0
AP Physics C:M		397	20.0
AP Physics C:EM		133	6.7
Non-AP		738	37.3
	Total	**1,981**	**100.0**

Note: Weighted, after exclusions.

Analysis of Questionnaire Data

TIMSS Advanced included questionnaires for students, teachers, and schools. The teacher and school questionnaire data were merged with the student questionnaire data, so that the results reflected the weighted proportions of students, rather than the numbers of teachers or schools responding.

Note to Readers About Questionnaire Data

The TIMSS Advanced sampling design produces a nationally representative sample of students in the target population. As a consequence, data from questionnaires given to teachers and school administrators are expressed in student units. In the report's discussion of teacher and school characteristics, for example, readers may encounter, "More than 80% of students were taught by a teacher with the following characteristic," or "More than 80% of students attended a school with the following characteristic," rather than seeing results reported as "percentage of teachers" or "percentage of schools." This convention sometimes leads to awkward language, but more precisely conveys the inferences that can be drawn from the study's data.

Estimating TIMSS Advanced Achievement Using Plausible Values

The TIMSS Advanced program publishes *plausible values* (e.g., von Davier, Gonzalez, and Mislevy 2009) as part of its statistical analysis for studying student achievement. In addition, plausible values are published for the convenience of secondary data-analysts, as the plausible values facilitate appropriate statistical inference when modeling student achievement on TIMSS Advanced. TIMSS Advanced also uses stratified sampling in its selection of schools and students within those schools. As a result, each student who ends up in the TIMSS sample is assigned a *sampling weight*[13] that must be incorporated into statistical analysis for proper inference.

Both of these features of TIMSS Advanced, plausible values and sampling weights, must be used appropriately to obtain proper estimates of achievement on TIMSS Advanced for subgroups, and corresponding standard errors. For instance, to estimate the mean TIMSS Advanced Math score for AP Calculus BC students, the plausible values and sampling weights must be incorporated.

While there are various statistical methods that can incorporate the plausible values and sampling weights, in our analyses, we used the same methods that were used operationally in TIMSS Advanced (LaRoche and Foy 2016). The accuracy of our implementation, coded using R software, was verified by reproducing various achievement tables published by the TIMSS & PIRLS International Study Center.

Estimating Correlations Among TIMSS and AP Exams

Given the similarity in content between AP and TIMSS Advanced exams that cover the same subject (e.g., TIMSS Advanced Math and AP Calculus BC), it stands to reason that student achievement on the two exams would be correlated. Because the TIMSS exams are scored using plausible values, calculating the correlations among the exams isn't straightforward. However, "linking" the exams provides a way to quantitatively study this relationship. To accomplish this linking, we used a version of the calibrated projection linking method proposed by Thissen et al. (2011).

Unlike TIMSS Advanced, AP does not use Item Response Theory (IRT) for test scoring. Consequently, it was necessary to perform IRT item calibrations for each AP subject test. These calibrations were performed using the entire population of AP Exam takers, for each subject test. For example, for AP Calculus AB, over 250,000 students were used in the calibration.

We conducted the "calibrated projection linking" using a two-dimensional confirmatory item response theory (IRT) model. For the present linking, the two dimensions correspond to achievement on the AP Exam (θ_{AP}), and achievement on TIMSS Advanced (θ_{TA}). The model allows a student to receive a distinct score estimate for each dimension, while simultaneously estimating the correlation between the two dimensions. This correlation estimate helps to quantify the similarity between the AP and TIMSS Advanced Exams.

Characteristics of the Students in the Study

This chapter describes the characteristics of the AP–TIMSS Advanced study samples with respect to student demographics and family background. The information summarized in

13. As with the questionnaire analysis, "house weights" were used.

this section is drawn from *TIMSS Advanced 2015 Student Questionnaire*, *Advanced Mathematics*, and *TIMSS Advanced 2015 Student Questionnaire, Physics*. Descriptions and comparisons are first given for the calculus students, followed by descriptions and comparisons for the physics students.

Student Demographics

As shown in Table 4, females and males were almost equally represented in the AP Calculus AB and the non-AP Calculus groups. For AP Calculus AB, 49.2% of the group was female and 50.8% was male. The AP Calculus BC group had a distribution favoring males, with 43.6% female and 56.4% male. The distribution for the non-AP group was the opposite of the AP Calculus AB group, with 50.8% of the group female and 49.2% of the group male.

The proportion of Hispanic or Latino students in the AP Calculus AB group was 20.9%, more than double the proportion of Hispanic or Latino students in the AP Calculus BC group, which was 8.1%. In the non-AP group, 12.6% of the students reporting that they were Hispanic or Latino. Students were asked about race separately from ethnicity: *Which of the following best describes you?* For the AP Calculus AB group, 75.4% of the responded White, 7.0% Black or African American, 13.8% Asian, 1.8% American Indian or Alaskan Native, and 1.0% Native Hawaiian or Pacific Islander. These proportions were very similar to the racial distribution of the non-AP Calculus group. Compared to the other groups, the AP Calculus BC group had a smaller percentage of students reporting their race as Black/African American (2.9%) and a larger percentage reporting their race as Asian (28.4%).

Table 4: Demographic Characteristics of Calculus Groups (Percentage)

Characteristic	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Females	49.2	43.6	50.8
Males	50.8	56.4	49.2
Hispanic/Latino	20.9	8.1	12.6
White	75.4	74.4	74.7
Black/African American	7.0	2.9	6.3
Asian	13.8	28.4	15.8
American Indian	1.8	4.6	1.7
Pacific Islander	1.0	0.5	1.6

Note: Percentages in racial categories may not sum to 100 as students were allowed to check more than one race.

Table 5 shows similar demographic information for the Physics groups. For AP Physics 1, 45.5% of the group was female and 54.5% was male. The AP Physics C:M group had a distribution that favored males, with 24.1% female and 75.9% male. The distribution for the AP Physics C:EM group also favored males, but to a lesser extent. The non-AP Physics group also favored males, with 40.4% female and 59.6% male.

The proportion of Hispanic or Latino students in the AP Physics 1 group was 23.6%, approximately twice the proportion of the other physics groups. Both the AP Physics 1 and the non-AP Physics groups had a larger Black/African American population. For all of the physics groups, the percentage of students who self-reported their race as White was between 64.8% and 74.2%.

Table 5: Demographic Characteristics of Physics Groups (Percentage)

Characteristic	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Females	45.5	24.1	30.2	40.4
Males	54.5	75.9	69.8	59.6
Hispanic/Latino	23.6	11.4	12.7	12.0
White	69.2	72.1	74.2	64.8
Black/African American	12.1	4.8	1.3	10.4
Asian	18.2	23.2	22.3	23.3
American Indian	1.7	0.7	0.4	2.0
Pacific Islander	1.0	1.4	0.9	1.5

Note: Percentages in racial categories may not sum to 100 as students were allowed to check more than one race.

Primary Language

Students were asked to respond to two questions related to the primary language spoken at home: *How often do you speak English at home? What language do you speak at home (other than English)?* Students responded to the first question on a four-point Likert scale. As shown in Table 6, for the calculus groups 86.6% of the AP Calculus AB group indicated that English was at least Almost Always spoken at home. This combined percentage was not statistically significantly different from the AP Calculus BC group (90.1%) or the non-AP Calculus group (92.4%).

Table 6: Calculus: English Spoken at Home (Percentage)

	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Always	70.3	73.7	77.3
Almost Always	16.3	16.4	15.1
Sometimes	10.0	8.1	5.4
Never	3.4	1.7	2.3

Students were asked about a second primary language ("always" English students are recorded as "not applicable" in Table 7). Over 30% of the AP Calculus AB group indicated that they spoke Spanish or some other language at home. Similarly, 25.6% of the AP Calculus BC group and 23.6% of the non-AP Calculus group spoke Spanish or another language at home, although the percentage of Spanish speakers was less in AP Calculus BC than in AP Calculus AB.

Table 7: Calculus: Spanish or Other Language Spoken at Home (Percentage)

	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Not applicable	69.2	74.4	76.4
Spanish	15.4	4.3	8.3
Other	15.4	21.3	15.3

The physics groups had results that were very similar to calculus for their primary language spoken at home. As shown in Table 8, 84.6% of the AP Physics 1 group indicated that English was at least *Almost Always* spoken at home. This combined percentage was higher for the AP Physics C:M group (86.6%) and the non-AP Calculus group (88.9%), and slightly lower for the AP Physics C:EM group (83.7%).

Table 8: Physics: English Spoken at Home (Percentage)

How often do you speak English at home?	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Always	65.6	72.9	70.3	68.6
Almost Always	19.0	13.7	13.4	20.3
Sometimes	12.3	8.9	9.9	8.7
Never	3.1	4.6	5.8	2.4

When asked about a second primary language (see Table 9), 34.6% of the AP Physics 1 group responded that they spoke Spanish (18.5%) or some other language at home (16.1%). For the other physics groups, between 25% and 30% of the students indicated that they spoke Spanish or another language at home.

Table 9: Physics: Spanish or Other Language Spoken at Home (Percentage)

What language do you speak at home (other than English)?	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Not applicable	65.5	73.6	70.8	69.2
Spanish	18.5	7.9	6.6	7.3
Other	16.1	18.6	22.5	23.1

It is important to note here that this represents a student population committed to completing the most advanced mathematics and science coursework offered in U.S. high schools. In general, more than one-fourth of these advanced students are in a home that at least sometimes speaks a language other than English. The percentage of students who speak Spanish at home is also noteworthy, as it represents 15.4% of the AP Calculus AB group and 18.5% of the AP Physics 1 group.

Socioeconomic Status

In international assessments, the socioeconomic status (SES) of students is often measured as a combination of parent characteristics and possessions in the home.[14] In the TIMSS Advanced survey, educational attainment of parents was demarcated along the lines of high school, postsecondary, and post-baccalaureate education. Students were asked to consider both parents on a scale ranging from completing less than high school education to earning a graduate degree.

Students in the most advanced AP classes hail from highly educated families. For the calculus groups, parents of the AP Calculus BC had the highest educational attainment with 34.4% of students' mothers and 39.2% of fathers earning a master's or doctoral degree. The corresponding figure for the U.S. population as a whole over the age of 25 is 15.0%.[15] The AP Calculus AB group's parents had the lowest educational attainment, with 33.7% of students' mothers and 34.2% of students' fathers completing a high school education or less.[16]

14. Jan-Eric Gustafsson, Kajsa Yang Hansen, and Monica Rosen, "Effects of Home Background on Student Achievement in Reading, Mathematics, and Science at the Fourth Grade," Chapter 4 in *TIMSS and PIRLS 2011 Relationships Report*, pp. 181-287.

15. "*Educational Attainment in the United States: 2014". U.S. Census Bureau*.

16. Response options were slightly different between the SPSS data file and the actual questionnaire (e.g., Asssociate's degree was "short-cycle tertiary"). Questionnaire wording included stepmother or female legal guardian and stepfather or male legal guardian.

Table 10: Calculus: Parents' Education (Percentage)

What is the highest level of education completed by your...?	AP Calculus AB		AP Calculus BC		Non-AP Calculus	
	Mother	Father	Mother	Father	Mother	Father
No high school diploma	10.7	11.6	5.1	6.4	5.6	6.1
High school graduate	23.0	22.6	15.8	15.7	16.7	20.3
Associate degree	15.1	9.2	12.4	6.5	15.4	9.5
Bachelor´s degree	29.7	28.9	31.3	28.2	34.2	29.8
Graduate Degree (Master, Doctorate, or Professional)	18.9	22.6	34.4	39.2	24.4	27.7
I don't know	2.5	5.1	1.1	3.9	3.7	6.5

For the physics groups, the AP Physics C:EM had the highest educational attainment with 41.6% of students' mothers and 52.7% of fathers earning a master's or doctoral degree. The AP Physics 1 group had students with parents who had the lowest educational attainment, with 32.1% of students' mothers and 33.7% of students' fathers completing a high school education or less. Given that students in AP Calculus AB and AP Physics 1 courses complete coursework that could earn them college credit, a large proportion of students in these courses may exceed the educational attainment of their parents.

Table 11: Physics: Parents' Education (Percentage)

What is the highest level of education completed by your...?	AP Physics 1		AP Physics C:M		AP Physics C:EM		Non-AP Physics	
	Mother	Father	Mother	Father	Mother	Father	Mother	Father
No High School Diploma	12.7	10.3	5.0	3.9	4.5	2.6	8.4	7.6
High school graduate	19.3	23.4	15.5	10.5	8.6	11.2	20.1	20.7
Associate degree	10.5	8.9	8.0	7.4	7.7	1.9	11.5	7.7
Bachelor´s degree	33.7	27.9	40.9	35.7	33.2	26.2	31.7	31.0
Graduate Degree (Master, Doctorate, or Professional)	21.3	25.5	28.5	39.7	41.6	52.7	25.3	28.1
I don't know	2.4	4.0	2.0	2.7	4.4	5.4	3.1	4.9

For the two AP Calculus groups and the three AP Physics groups, between 45% and 65% of the students report having enough books in their home to fill at least two bookcases. The non-AP Calculus and non-AP Physics groups have responses in this same range of percentages.

Table 12: Calculus: Books in Home (Percentage)

About how many books are there in your home?	AP Calculus AB	AP Calculus BC	Non-AP Calculus
None or very few (0–10 books)	7.2	4.7	5.4
Enough to fill one shelf (11–25 books)	15.2	8.2	13.5
Enough to fill one bookcase (26–100 books)	31.4	29.2	26.5
Enough to fill two bookcases (101–200 books)	20.1	24.4	24.6
Enough to fill three or more bookcases (more than 200)	26.0	33.5	29.9

Table 13: Physics: Books in Home (Percentage)

About how many books are there in your home?	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
None or very few (0–10 books)	8.2	3.4	1.9	6.2
Enough to fill one shelf (11–25 books)	12.8	8.6	6.6	13.0
Enough to fill one bookcase (26–100 books)	29.7	24.9	24.3	30.1
Enough to fill two bookcases (101–200 books)	24.0	27.1	27.3	23.0
Enough to fill three or more bookcases (more than 200)	25.3	35.9	39.8	27.7

Access to *digital devices in the home* is a potential indicator of several student characteristics. Due to the expense of purchasing and maintaining digital devices it is partially related to SES. In addition, however, access to various technology platforms may represent student familiarity with the internet and access to resources that could support increased educational attainment. Responding to a series of general questions (data not shown), over three quarters of students in all calculus and physics groups indicated that they have at least seven or more digital information devices in their homes.

Of course, digital devices that are shared by an entire family may limit access. Two items that examined this issue further asked students whether they have their own digital devices along with other possessions. Among all calculus and physics groups, over 90% of students had their own smartphone, over 80% their own computer, and approximately 50% their own car. Given that AP Calculus requires the use of a graphing calculator on some sections of the exam, it could be a concern that up to 15% of AP Calculus students do not own a graphing calculator. Interestingly, only 5% of AP Physics C students do not own a calculator; however, for the AP Physics 1 and non-AP groups, almost 20% of students donot own a graphing calculator.

Table 14: Calculus: Digital Devices and Other Personal Possessions (Percentage)

Do you have any of these things?	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Your own computer	81.4	85.0	80.1
Your own tablet	38.7	38.0	39.0
Your own smartphone	93.7	91.2	92.4
Your own graphing calculator	84.9	87.6	85.5
A gaming system (e.g., PlayStation, Wii, Xbox)	80.6	77.1	76.6
Study desk/table for your use	83.5	89.2	85.4
Your own room	88.1	91.0	91.2
Your own car	53.7	50.3	56.2

Table 15: Physics: Digital Devices and Other Personal Possessions (Percentage)

Do you have any of these things?	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Your own computer	86.1	85.8	87.1	82.7
Your own tablet	33.9	33.7	39.0	37.7
Your own smartphone	93.8	91.6	95.0	93.8
Your own graphing calculator	81.4	94.6	95.2	80.2
A gaming system (e.g., PlayStation, Wii, Xbox)	74.4	84.5	79.1	78.0
Study desk/table for your use	83.6	86.8	89.1	84.7
Your own room	85.1	91.1	90.9	88.6
Your own car	46.4	51.6	51.8	48.3

Students also responded to survey items on weekly time commitments—specifically, students reported the time they spent inside and outside of school studying math or science, if they had a job during the school year and, if they did, the weekly time devoted to that job.

In mathematics classes, both AP Calculus groups indicated that they spent, on average, close to five hours per week in class; the non-AP Calculus group spent about four hours per week in class. The difference between the non-AP group and the two AP groups is about 56 minutes, longer than a single class period in many high schools. The weekly time spent on mathematics outside of class ranged from 3 hours, 15 minutes for AP Calculus BC to 2 hours, 43 minutes for AP Calculus AB, to 1 hour, 32 minutes for the non-AP Calculus group. As the combined time figures show, non-AP students spend dramatically less time each week, at least two hours, engaged with mathematics than AP students. The difference is both statistically and substantively significant. Over a 36-week course, the shortfall would accumulate to at least 72 hours.

Table 16: Calculus: Time Spent Per Week on Mathematics, Mean (Standard Error) in Hours: Minutes

Weekly Time Spent	AP Calculus AB	AP Calculus BC	Non-AP Calculus
In Mathematics Class	4:55 (0:08)	4:55 (0:10)	3:59 (0:09)
On Mathematics Outside of Class	2:43 (0:09)	3:15 (0:16)	1:32 (0:05)
Combined Time	7:37 (0:12)	8:10 (0:21)	5:32 (0:12)

In physics, the three AP Physics groups responded that they spent between 4 hours, 30 minutes and 4 hours, 47 minutes per week in class. The non-AP Physics group spent 3 hours, 25 minutes per week in class. The time spent on physics outside of class ranged from just over two hours per week for AP Physics C:M and AP Physics C:EM, to 1 hour, 19 minutes per week for the non-AP Physics group. AP Physics 1 students spent just under 2 hours per week on physics outside of class. Similar to the calculus groups, the non-AP students spent less time engaged with physics either in or outside of class.

Table 17: Physics: Time Spent Per Week on Physics, Mean (Standard Error) in Hours: Minutes

Weekly Time Spent	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
In Physics Class	4:31 (0:08)	4:30 (0:12)	4:47 (0:17)	3:25 (0:10)
On Physics Outside of Class	1:53 (0:07)	2:06 (0:09)	2:05 (0:15)	1:19 (0:08)
Combined Time	6:25 (0:13)	6:36 (0:18)	6:52 (0:26)	4:45 (0:13)

When not attending school or studying school subjects, teenagers may engage in paid employment. Around the world, working during the school year is rare for TIMSS Advanced students, and it is especially unusual to devote more than 10 hours per week to paid employment (see Table 18). The two outliers are Norway and the United States. In Norway, 18% of advanced math students and 15% of advanced physics students report working more than 10 hours per week. In the U.S., 20% of advanced math students and 21% of physics students work more than 10 hours per week.

Table 18: TIMSS Advanced Students Working More Than 10 Hours per Week at a Paid Job During the School Year

Country	Mathematics (%)	Physics (%)
France	1 (0.1)	0 (0.1)
Italy	3 (0.4)	2 (0.3)
Lebanon	3 (0.7)	2 (0.4)
Norway	18 (1.9)	15 (0.9)
Portugal	3 (0.3)	2 (0.3)
Russian Federation	3 (0.2)	2 (0.3)
Slovenia	5 (0.5)	4 (0.6)
Sweden	6 (0.4)	5 (0.5)
United States	20 (1.2)	21 (1.6)
International Avg.	7 (0.3)	6 (0.2)

Source: IEA's Trends in International Mathematics and Science Study–TIMSS Advanced 2015 Exhibits M4.2 and P4.2.

Table 19 displays data on employment for students in the study's analytical groups. Approximately 30%–40% of students in advanced mathematics and physics courses had a part time job while they were in school. Among all groups, the non-AP Calculus group (40.5%) had the highest proportion of students who were employed and the AP Physics C:M group had the lowest rate of employment (29.4%). Of those students who were employed, the mean hours per week spent at their paid job ranged from a high of 16 hours, 45 minutes for AP Physics 1 to a low of 9 hours, 35 minutes for AP Physics C:EM.

Table 19: Time Spent Working at a Paid Job During the School Year

	AP Calculus AB	AP Calculus BC	Non-AP Calculus	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Do Not Work (%)	68.1 (2.2)	70.2 (4.4)	59.5 (3.8)	70.4 (3.7)	70.6 (2.9)	67.6 (4.6)	65.4 (4.0)
Work During the School Year (%)	31.9 (2.2)	29.8 (4.4)	40.5 (3.8)	29.6 (3.7)	29.4 (2.9)	32.4 (4.6)	34.6 (4.0)
Weekly Time Spent by Working Students (Hours:Minutes)	14:42 (0:34)	13:19 (0:56)	14:04 (1:03)	16:45 (0:46)	14:12 (0:41)	9:35 (1:07)	14:27 (1:08)

Achievement

This section examines scores on the 2015 TIMSS Advanced tests for mathematics and physics. First, to illustrate the comparability of the math and physics skills tested, the correlations among the relevant TIMSS and AP tests are presented. These results complement the qualitative comparisons from the alignment study cited earlier. Then, to gain a global perspective, results for AP Calculus and AP Physics—and their non-AP counterparts—are presented, along with the scores of other education systems that participated in the 2015 TIMSS Advanced. The analysis then turns to how the study's sample groups performed on the content and cognitive subdomains of TIMSS Advanced. The section ends with a look at gender differences on the tests.

The correlations among the AP and TIMSS score scales for the relevant comparisons are reported in Table 20. The sample sizes on which these correlations are based are also reported. The largest correlations are for Calculus AB and TIMSS Advanced Math, and for AP Physics 1, and TIMSS Advanced Physics. The smallest correlation was between AP Calculus AB and TIMSS Advanced Math, but even that correlation was large (r=.77). These results indicate strong correspondence in each subject area regarding students' performance across the TIMSS and AP Exams. These results also complement the more in-depth previously released alignment study—*TIMSS Advanced 2015 and Advanced Placement Calculus & Physics—A Framework Analysis* (Lazzaro et al. 2016).

CollegeBoard

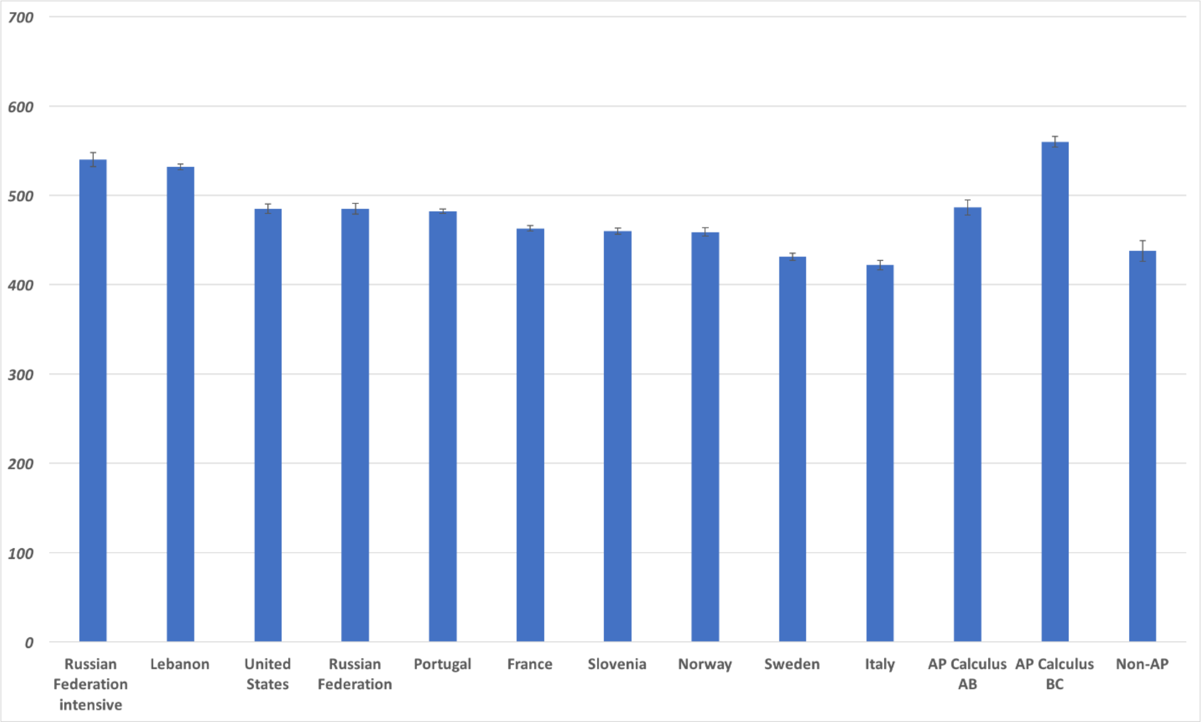
Table 20: Correlations Among AP and TIMSS Scores

	TIMSS Math	
AP Exam	**n**	**r**
Calculus AB	1,301	.93
Calculus BC	395	.77
	TIMSS Physics	
	n	**r**
Physics 1	747	.91
Physics C:M	469	.80
Physics C:EM	141	.86

The TIMSS Advanced Mathematics scores for participating education systems and AP Calculus groups are shown in Figure 1. The United States performed in the upper half of participating countries, scoring almost the same as the Russian Federation and behind Lebanon. The highest-performing system was the Russian Federation Intensive Course group, which required more than six hours a week of mathematics instruction. The lowest-performing countries on the TIMSS Advanced Mathematics were Sweden and Italy.

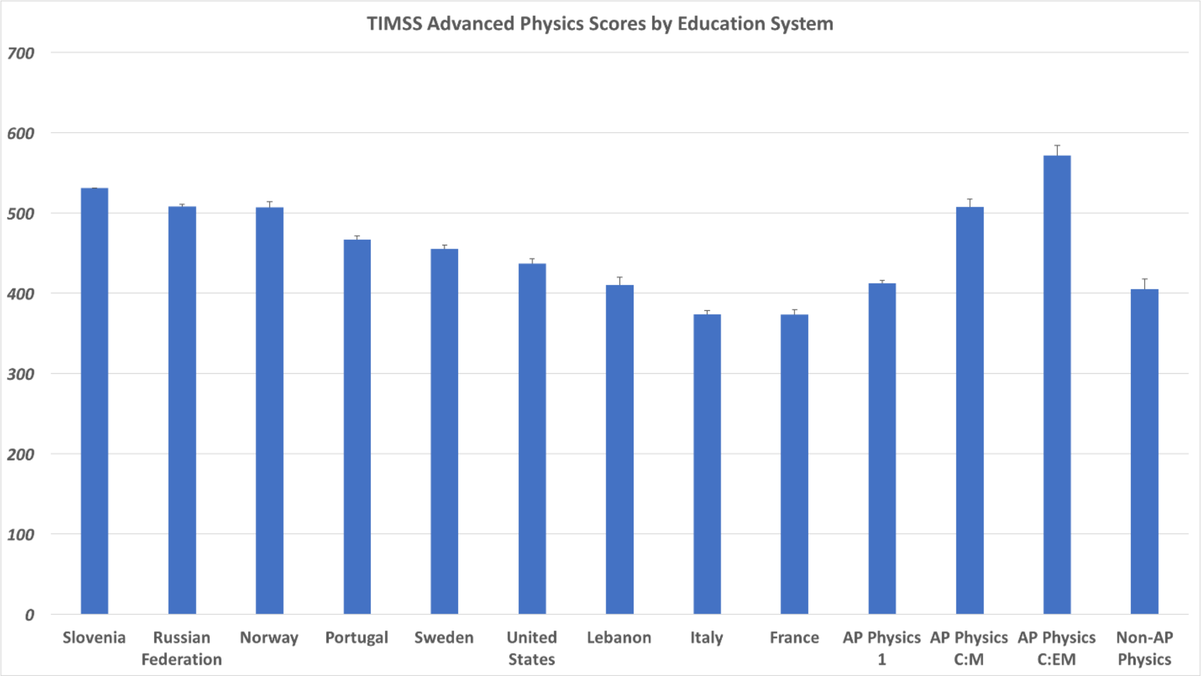
The scores for the current study's calculus groups are depicted by the final three bars on the right side of the figure. Of these three groups, the non-AP Calculus group performed at a level comparable to Sweden and under the overall performance of the United States. The performance of the AP Calculus AB group was comparable to overall performance of the United States. The AP Calculus BC group's performance exceeded all participating education systems's national average scores and that of the other AP Calculus groups.

Figure 1: TIMSS Advanced Mathematics Scores by Education System and AP Groups



The TIMSS Advanced Physics scale scores for participating education systems and AP Physics groups are shown in Figure 2. The United States performed in the bottom half of participating countries, just ahead of Lebanon. The highest-performing country was Slovenia and the lowest-performing countries were Italy and France. The physics scores for the sample groups selected for this study are shown on the right side of the figure. Of these four groups, the non-AP Physics and AP Physics 1 groups performed at a level comparable to Lebanon. The AP Physics C:M group's performance was comparable to the Russian Federation and Norway. The AP Physics C:EM group's performance exceeded all participating education systems and AP Physics groups.

Figure 2: TIMSS Advanced Physics Scores by Education System and AP Groups



Tables 21 and 22 display change in test scores over time. The U.S. last participated in TIMSS Advanced in 1995. The change in test scores from 1995–2015 is presented in the far right column of both tables. Also shown is each participating system's coverage index, which, as described in section 2, is a measure of selectivity. As a reminder, the coverage index represents the percentage of the relevant age cohort enrolled in advanced math and physics courses; the total enrollment in those courses constitutes the TIMSS Advanced target population. In the U.S., the age cohort is considered all 18-year-olds as of July 1, 2015, with the coverage index representing the percentage enrolled in advanced math or physics courses in 2015.

Compared with their results in 1995, TIMSS Advanced scores for all education systems in 2015 were apparently lower (see Table 21). The U.S. coverage index in advanced mathematics increased from 6.4% in 1995 to 11.4% in 2015. The apparent U.S. decline of 12 scale score points was not statistically significant. Of the three nations with statistically significant declines, France and Italy both increased the proportion of students in advanced math. Sweden's 71-point decline was despite its coverage index falling from 16.2% to 14.1%.

Table 21: Change in TIMSS Advanced Mathematics Score and Coverage Index, 1995-2015

Country	Year	Coverage Index	Average Scale Score	Scale Score Change 1995-2015
France	2015	21.5%	463 (3.1)	-107*
	1995	19.9%	569 (3.9)	
Italy	2015	24.5%	422 (5.3)	-61*
	2008	19.7%	449 (7.2)	
	1995	14.1%	483 (9.8)	
Lebanon	2015	3.9%	532 (3.1)	
	2008	5.9%	545 (2.2)	
Norway	2015	10.6%	459 (4.6)	
	2008	10.9%	439 (4.9)	
Russian Federation 6hr+	2015	1.9%	540 (7.8)	-9
	2008	1.4%	561 (7.0)	
	1995	2.0%	549 (8.2)	
Slovenia	2015	34.4%	460 (3.4)	-18
	2008	40.5%	457 (4.3)	
	1995	75.4%	478 (9.3)	
Sweden	2015	14.1%	431	-71*

			(4.0)	
	2008	12.8%	412 (5.6)	
	1995	16.2%	502 (5.2)	
United States	2015	11.4%	485 (5.2)	-12
	1995	6.4%	497 (7.4)	

Note: * a statistical difference of p <.05

Source: Adapted from Exhibit M1.4 in TIMSS Advanced 2015

As shown in Table 22, four systems experienced statistically significant declines in advanced physics scores: France, Norway, Russian Federation, and Sweden. The apparent 16-point difference between 1995 and 2015 was not statistically significant. The U.S. coverage index increased from 2.7% in 1995 to 4.8% in 2015. In both math and science, the U.S. managed to raise the proportion of students taking advanced math and science courses without suffering statistically significant declines in achievement.

Table 22: Change in TIMSS Advanced Physics Score and Coverage Index, 1995–2015

Country	Year	Coverage Index	Average Scale Score	Scale Score Change 1995–2015
France	2015	21.5%	373 (4.0)	-96*
	1995	19.9%	469 (5.3)	
Italy	2015	18.2%	374 (6.9)	
	2008	3.8%	422 (7.4)	
Lebanon	2015	3.9%	410 (4.5)	
	2008	5.9%	444 (3.0)	
Norway	2015	6.5%	507 (4.6)	-74*

	2008	6.8%	534 (4.1)	
	1995	8.4%	581 (5.5)	
Russian Federation	2015	4.9%	508 (7.1)	-38*
	2008	2.6%	521 (10.1)	
	1995	1.5%	546 (10.1)	
Slovenia	2015	7.6%	531 (2.5)	-1
	2008	7.5%	535 (2.2)	
	1995	38.6%	532 (13.5)	
Sweden	2015	14.3%	455 (5.9)	-123*
	2008	11.0%	497 (5.3)	
	1995	16.3%	578 (3.7)	
United States	2015	4.8%	437 (9.7)	-16
	1995	2.7%	454 (8.1)	

Note: * a statistical difference of p <.05

Source: Adapted from Exhibit P1.4 in TIMSS Advanced 2015

Percentage of Students Reaching International Benchmark

To provide a more meaningful way to interpret scale scores on the TIMSS Advanced tests, the TIMSS International Study Center identifies *Advanced, High,* and *Intermediate* benchmarks. The TIMSS Advanced tests, in contrast to other TIMSS tests for fourth grade and eighth grade, did not establish a Low benchmark given the level of mathematics and science content and relative difficulty of the advanced tests. For more info on the TIMSS Advanced international benchmarks, see https://nces.ed.gov/timss/timss15technotes.

Table 23 summarizes the percentage of students in the AP Calculus groups and the United States who reached the international performance benchmarks for TIMSS Advanced mathematics. The percentages of students in the U.S. groups who reached the Advanced, High and Intermediate benchmarks were higher than the international medians for those benchmarks, which reflects the group's overall higher performance. The percentage of students in the AP Calculus AB group who reached all three benchmarks was comparable to the percentage for U.S. students as a whole. In sharp contrast, over 20% of students in the AP Calculus BC group reached the Advanced benchmark, and more than twice the percentage of students reached the High benchmark compared to the U.S. as a whole. In general, both AP Calculus groups had percentages of students reaching the Advanced and High benchmarks that were well above the international median. That was not true for the non-AP Calculus group.

Table 23: Percentage of Students Reaching International Benchmarks in Advanced Mathematics

	Percentage of Students Reaching Each International Benchmark		
Group (TIMSS Cut Score)	**Advanced (625)**	**High (550)**	**Intermediate (475)**
United States (AP + Non-AP)	7 (1.2)	26 (1.6)	56 (2.5)
AP Calc AB	6 (1.5)	25 (2.7)	59 (3.7)
AP Calc BC	21 (4.3)	57 (4.8)	86 (2.8)
Non-AP	1 (1.2)	8 (3.3)	35 (6.3)
International Median	2	14	43

Table 24 shows the percentage of students who reached the TIMSS Advanced international performance benchmarks for physics; the last row includes the international median as a reference. The percentages of students in the U.S. group who reached the Advanced and High benchmarks were comparable to the international medians for those benchmarks, but the percentage reaching the Intermediate threshold (39%) fell short of the international median (46%). The AP Physics 1 and non-AP Physics groups had lower percentages of students meeting each benchmark than the international medians. The percentage of students in the AP Physics C:M group was approximately double the international median for the Advanced and High benchmarks. Over one-quarter of the students in the AP Physics C:EM group reached the Advanced benchmark (27%), and nearly two-thirds (64%) reached the High benchmark.

Table 24: Percentage of Students Reaching International Benchmarks in Advanced Physics

	Percentage of Students Reaching Each International Benchmark		
Group	**Advanced (625)**	**High (550)**	**Intermediate (475)**
United States (AP + Non-AP)	5 (0.9)	18 (2.1)	39 (3.3)
AP Physics 1	1 (0.7)	9 (1.7)	30 (3.6)
AP Physics C:M	10 (2.5)	35 (5.4)	65 (5.7)
AP Physics C:EM	27 (8.5)	64 (7.3)	87 (5.0)
Non-AP	3 (1.8)	12 (5.9)	28 (7.7)
International Median	5	18	46

Content Domain Scores

The content domains addressed on the 2015 TIMSS Advanced mathematics test included advanced algebra, geometry, and calculus. Table 25 summarizes the overall results for the United States and the mean scores for the two AP Calculus groups and the non-AP group.

The highest advanced mathematics subscore for the United States was in calculus, and the lowest scores were in algebra and geometry. This pattern held for all U.S. mathematics groups including the non-AP Calculus group, not surprising considering that the U.S. is unique in organizing curricula addressing the three TIMSS Advanced content domains into separate, yearlong courses. Most of the world interweaves algebra, calculus, and geometry within advanced math courses, including the advanced math course taken in 2015. U.S. students, on the other hand, may not have had extensive exposure to algebra or geometry for one or more years.

The AP Calculus BC group was the highest-performing mathematics group, with content subscores that were also the highest for all U.S. groups. The AP Calculus AB group had the next highest set of subscores, which were comparable to the overall United States group. The non-AP calculus group was the lowest-performing group on the TIMSS Advanced Mathematics, by a large margin. Scoring highest in calculus was not the tendency for other countries. Both Russian Federation groups had higher subscores on algebra and geometry than their overall scores, but they had lower subscores in calculus. Portugal and Slovenia were stronger in algebra and weaker in calculus and geometry.

Table 25: Advanced Mathematics Content Domain Scores

Country or Group	Overall Advanced Mathematics Average Scale Score	Algebra (37 items) Ave. Scale Score	Algebra (37 items) Difference from Overall Advanced Math Score	Calculus (34 items) Ave. Scale Score	Calculus (34 items) Difference from Overall Advanced Math Score	Geometry (30 items) Ave. Scale Score	Geometry (30 items) Difference from Overall Advanced Math Score
Russian Federation intensive courses	540 (7.8)	556 (9.0)	16 (3.9)	513 (8.0)	-27 (2.3)	560 (8.4)	20 (3.2)
Lebanon	532 (3.1)	525 (4.0)	-6 (3.6)	544 (3.9)	12 (2.8)	526 (3.7)	-6 (2.3)
United States	485 (5.2)	478 (5.0)	-7 (1.7)	504 (6.0)	19 (2.9)	455 (5.7)	-30 (2.6)
AP Calculus AB	486 (8.5)	481 (8.7)	-6 (3.3)	509 (10.0)	22 (4.6)	454 (9.2)	-32 (2.8)
AP Calculus BC	560 (5.7)	551 (4.8)	-9 (4.0)	587 (6.3)	27 (5.2)	528 (5.3)	-32 (4.5)
Non-AP	438 (11.5)	430 (10.9)	-8 (3.7)	447 (11.4)	9 (4.4)	412 (11.8)	-26 (5.1)
Russian Federation	485 (5.7)	495 (6.3)	10 (1.9)	459 (5.9)	-26 (1.2)	500 (5.8)	15 (1.0)
Portugal	482 (2.5)	495 (2.7)	12 (1.5)	476 (2.6)	-6 (1.4)	464 (3.2)	-18 (1.5)
France	463 (3.1)	469 (2.9)	7 (1.8)	466 (3.2)	3 (1.8)	441 (3.7)	-22 (1.3)
Slovenia	460 (3.4)	474 (3.5)	14 (1.1)	437 (4.4)	-23 (2.0)	456 (4.0)	-4 (1.4)
Norway	459 (4.6)	446 (4.1)	-13 (1.6)	463 (5.3)	4 (1.5)	473 (4.6)	14 (2.0)
Sweden	431 (4.0)	422 (4.1)	-9 (1.2)	438 (3.9)	7 (1.5)	430 (3.7)	-1 (1.4)
Italy	422 (5.3)	414 (5.1)	-8 (2.2)	433 (5.2)	11 (2.7)	413 (5.7)	-9 (3.2)

The content domains addressed on the 2015 TIMSS Advanced physics test included mechanics and thermodynamics, electricity and magnetism, and wave phenomena and atomic/nuclear physics. Table 26 summarizes the overall results for the United States and the mean scores for each of the AP Physics groups and the associated non-AP group.

The highest physics subscore for the United States was Mechanics and Thermodynamics. The other two content domains subscores were lower than the overall scale score. As noted in Table 26, the AP Physics C:EM group was the highest-performing group in the study and that group’s content subscores are also the highest for all U.S. groups. The AP Physics C:M, AP Physics 1, and the Non-AP Physics groups had successively decreasing scores in all content subscores, with the Mechanics and Thermodynamics subscore greater than the overall mean and the other two content subscores less than the overall mean for all three groups. This pattern in content subscores was particular to the U.S. and did not necessarily hold for all education systems. For example, Italy, Norway, and the Russian Federation had Electricity and Magnetism subscores that were greater than their respective overall mean scores. Lebanon and France had Wave Phenomena and Atomic/Nuclear subscores that were greater than their respective overall mean scores, and their other two content subscores were less than their respective overall mean scores.

Table 26: Advanced Physics Content Domain Scores

		Mechanics and Thermodynamics (39 items)		Electricity and Magnetism (27 items)		Wave Phenomena and Atomic/Nuclear Physics (35 items)	
Country or Group	**Overall Physics Average Scale Score**	**Ave. Scale Score**	**Difference from Overall Advanced**	**Ave. Scale Score**	**Difference from Overall Advanced**	**Ave. Scale Score**	**Difference from Overall Advanced**
Slovenia	531 (2.5)	541 (2.7)	10 (1.6)	530 (4.3)	-1 (4.5)	511 (4.5)	-20 (3.9)
Russian Federation	508 (7.1)	514 (6.7)	7 (1.6)	515 (8.0)	8 (2.8)	490 (7.5)	-17 (2.1)
Norway	507 (4.6)	503 (4.1)	-5 (1.7)	514 (5.5)	7 (3.8)	507 (5.2)	0 (2.1)
Portugal	467 (4.6)	489 (4.8)	22 (3.2)	431 (5.8)	-35 (4.5)	456 (6.2)	-11 (5.2)
Sweden	455 (5.9)	455 (6.1)	0 (2.7)	455 (6.0)	1 (2.6)	451 (6.3)	-4 (2.7)
United States	437 (9.7)	462 (9.6)	25 (3.4)	379 (12.2)	-58 (3.9)	431 (8.7)	-7 (3.0)
AP Physics 1	412 (9.8)	442 (9.8)	30 (4.0)	347 (10.6)	-66 (5.3)	409 (8.7)	-3 (4.4)
AP Physics C:M	508	534	27	471	-36	490	-17

	(12.2)	(12.4)	(4.7)	(16.3)	(7.5)	(10.5)	(5.7)
AP Physics C:EM	572 (13.2)	588 (11.1)	16 (10.4)	553 (17.0)	-18 (11.5)	545 (10.7)	-26 (10.1)
Non-AP	405 (23.0)	427 (22.0)	22 (5.4)	336 (31.3)	-69 (10.4)	406 (23.5)	2 (6.6)
Lebanon	410 (4.5)	395 (4.4)	-15 (4.7)	399 (5.2)	-11 (5.9)	431 (6.8)	20 (5.7)
Italy	374 (6.9)	376 (6.4)	2 (2.6)	425 (6.6)	51 (3.7)	329 (7.9)	-45 (2.3)
France	373 (4.0)	327 (5.7)	-46 (3.7)	339 (4.7)	-34 (3.8)	418 (4.5)	45 (2.5)

Note: AP student categories based on AP exam-taking. The category “Non-AP” students excludes all students who took an AP course but did not take the AP exam in 2015.

Cognitive Domain Scores

For both subjects, three cognitive domains of knowing, applying, and reasoning were articulated in the 2015 TIMSS Advanced framework. Each of these three domains is in turn described by a set of specific thinking skills and behaviors for math and physics. The framework states that while there is some hierarchy across these three Cognitive Domains, from knowing to applying to reasoning, each domain is assessed with items representing a full range of difficulty.

In mathematics, tasks can elicit different types of thinking processes or skills, from the recall of mathematical terms and algorithms, to the application of mathematics knowledge in different contexts, to reasoning that involves further generalization of mathematical relationships. Student performance disaggregated by cognitive domain for the participating education systems, and the AP Calculus groups, is summarized in Table 27.

Table 27: Advanced Mathematics Cognitive Domain Scores

Country or Group	Knowing	Applying	Reasoning
Norway	445 (4.1)	459 (5.1)	469 (4.4)
Slovenia	466 (3.5)	465 (4.0)	442 (4.0)
Russian Federation	478 (6.7)	491 (6.1)	484 (5.3)
Russian Federation Intensive Courses	538 (8.8)	544 (8.1)	541 (7.2)

Portugal	479 (3.0)	476 (2.9)	488 (3.5)
United States	488 (5.7)	480 (5.5)	484 (5.3)
AP Calculus AB	491 (9.4)	482 (9.0)	486 (8.7)
AP Calculus BC	567 (6.3)	552 (5.5)	559 (6.4)
Non-AP	426 (12.3)	432 (12.7)	437 (11.5)
Sweden	405 (4.7)	434 (3.6)	447 (3.9)
France	475 (2.7)	449 (3.4)	462 (3.1)
Italy	423 (5.5)	425 (5.4)	411 (5.9)
Lebanon	453 (4.5)	529 (3.8)	527 (3.9)

Education systems have relative strengths and weaknesses. France and Lebanon demonstrated relatively higher performance in the knowing domain compared to their students' scores for other cognitive domains. Norway and Sweden had relatively higher performance in the reasoning domain. The AP Calculus AB and AP Calculus BC groups had somewhat consistent performance across the cognitive domains, which is similar to overall performance for the United States. The AP Calculus BC group had the highest mean score for knowing. The performance of AP Calculus BC group for applying and reasoning, taking into account the standard error for each mean, was similar to that of students in Russian Federation Intensive Course. The performance of the non-AP Calculus group was low across the cognitive domains, and was comparable to the performance of Italy among education systems.

The data summarized in Table 28 indicate that students in all three of the AP Physics courses are preforming highly on reasoning tasks. Indeed, students in Physics C:M and Physics C:EM are performing among the highest scoring countries in that domain. College Board has dedicated considerable time and effort to ensuring that the AP science assessments focus on reasoning. AP science courses ask students to analyze and synthesize data, to design investigations and formulate hypotheses, and to engage in argumentation and justify conclusions based on scientific evidence. This emphasis is evident in the AP science and TIMSS Advanced frameworks.

It is also worth noting that no significant difference is observed between the non-AP group and the AP Physics 1 students. Bearing in mind that this is the first year AP Physics 1 was offered, the average scores for each of the cognitive domains is surprisingly similar to the non-AP group. This is similar to what was observed in the content subscores between AP Physics 1 and non-AP. The overall U.S. cognitive domain averages are again elevated by the considerably higher scores of AP Physics C:M and AP Physics C:EM students.

Table 28: Advanced Physics Cognitive Domain Scores

Country or Group	Knowing	Applying	Reasoning
Norway	529 (4.2)	484 (5.3)	519 (5.7)
Slovenia	521 (4.2)	543 (3.8)	514 (5.7)
Russian Federation	517 (7.5)	508 (7.6)	493 (6.7)
Portugal	474 (4.7)	452 (5.7)	481 (3.9)
United States	444 (9.8)	420 (10.2)	455 (8.8)
AP Physics 1	418 (12.1)	392 (8.6)	436 (8.9)
AP Physics C:M	514 (11.7)	490 (13.0)	519 (9.9)
AP Physics C:EM	575 (12.3)	559 (13.1)	575 (13.7)
Non-AP	411 (23.8)	386 (23.6)	425 (21.4)
Sweden	452 (6.0)	454 (6.4)	450 (6.2)
France	375 (3.9)	358 (5.6)	397 (4.2)
Italy	367 (6.6)	371 (7.3)	375 (7.3)
Lebanon	378 (4.7)	433 (5.4)	375 (6.2)

Gender Differences

Given the historical issues of access and participation of women in mathematics and science, an analysis of gender differences in student performance on the TIMSS Advanced exams was warranted. Table 29 summarizes the mean performance of females and males on the TIMSS Advanced Mathematics assessment for the participating countries and the AP Calculus groups. The education systems are sorted by the difference in mean performance, from positive differences favoring females to negative differences. With respect to the participation of students by gender, Slovenia had a female-to-male participation ratio of 60:40, Portugal was 51:49, Russian Federation was 50:50, and the United States was 49:51. Lebanon had the greatest participation ratio favoring males at 36:64.

In comparing mean performance on the TIMSS Advanced Mathematics exam by gender, Italy was the only country that had positive differences in performance favoring females that were greater than the standard error. Lebanon and Portugal were the only two countries that had differences less than the standard error. All of the other participating countries had differences favoring males on the TIMSS Advanced Mathematics exam, with the United States having the greatest difference among countries favoring males. The performance of the AP Calculus AB group stands out from the other United States groups given the difference of only 9 scale score points. AP Calculus BC had the highest scoring group of female students; however, this group also had the largest difference favoring males, even larger than the overall performance for the United States. The non-AP Calculus group had a difference in performance favoring males that was similar to the gender difference for the United States.

Table 29: Gender Differences in TIMSS Advanced Mathematics Scores

Country	Females	Males	Difference
Italy	427 (6.1)	419 (6.6)	+ 8 (7.5)
Lebanon	533 (4.8)	531 (3.9)	+ 2 (6.1)
Portugal	481 (3.0)	483 (3.1)	- 2 (3.6)
Russian Federation	480 (6.0)	489 (6.2)	- 9 (4.3)
Norway	453 (5.1)	463 (5.2)	- 10 (4.8)
Sweden	424 (5.1)	436 (4.6)	- 13 (5.3)
Russian Federation Intensive	530	549	- 20

Courses	(9.0)	(7.5)	(5.2)
France	449 (3.1)	475 (3.4)	- 26 (2.8)
Slovenia	449 (3.5)	476 (4.9)	- 27 (4.7)
United States	470 (5.3)	500 (6.4)	- 30 (5.8)
AP Calculus AB	482 (7.9)	491 (7.9)	- 9 (12.1)
AP Calculus BC	539 (7.3)	575 (7.3)	- 36 (9.4)
Non-AP	425 (11.1)	453 (15.5)	- 28 (13.6)

Table 30 summarizes the mean performance of females and males on the TIMSS Physics exam for the participating countries and the AP Physics groups. As with Table 29, the education systems are sorted by the difference in mean performance, from positive differences favoring females to negative differences. With respect to the participation of students by gender, no country had a female-to-male participation ratio favoring females. France had a female-to-male participation ratio of 47:53, Russian Federation was 42:59, and the United States was 39:61. Portugal had the greatest participation ratio favoring males at 25:75.

In comparing mean performance on the TIMSS Physics exam by gender, Lebanon was the only country that had a difference in performance favoring females. All of the other participating countries had differences favoring males on the TIMSS Physics exam, with the United States having the greatest difference among countries favoring males. The performance of the AP Physics C:EM and AP Physics 1 had a difference in mean performance favoring males that was similar to the gender difference for the United States. The difference in mean performance by gender for the non-AP Physics and AP Physics C:M groups was less than that for the United States. In general, for the United States the gender differences on the TIMSS Physics exam were greater than that for the TIMSS Advanced Mathematics exam, although the differences favoring males for six of the seven U.S. groups are large and significant.

Table 30: Gender Differences in TIMSS Physics Scores

Country	Females	Males	Difference
Lebanon	417 (5.2)	406 (6.4)	+ 11 (8.2)
Sweden	448	459	- 11

	(6.1)	(6.6)	(4.9)
Portugal	456 (6.2)	470 (5.1)	- 14 (6.8)
Russian Federation	498 (7.9)	514 (7.3)	- 16 (5.8)
Norway	489 (6.0)	515 (4.8)	- 26 (5.3)
Slovenia	510 (6.5)	540 (3.7)	- 29 (8.6)
Italy	356 (7.3)	389 (8.4)	- 32 (7.8)
France	354 (4.2)	390 (4.6)	- 35 (3.8)
United States	409 (11.9)	455 (9.3)	- 46 (7.1)
AP Physics 1	390 (10.4)	431 (10.4)	- 41 (11.6)
AP Physics C:M	488 (19.5)	514 (11.3)	- 26 (16.3)
AP Physics C:EM	539 (20.7)	585 (13.0)	- 46 (18.9)
Non-AP	386 (27.0)	418 (21.7)	- 32 (13.1)

Linking TIMSS and AP: Mean TIMSS Advanced Score by AP Score Groups

AP students take an exam at the end of each AP course, with scores awarded on a 1 (lowest) to 5 (highest) scale. Scores of 3 and above are conventionally considered passing scores, and many colleges and universities award college credit to students attaining such scores. Is there a relationship between AP Exam scores and TIMSS scores?

Table 31 displays the mean TIMSS Advanced score for AP students, disaggregated by those who scored above and below the “3” threshold.[17] The differences in TIMSS means are large, as shown in the far right column. Consider that the established standard deviation of TIMSS Advanced assessments is 100. Four of the five AP group differences are larger than 100 points, and the smallest difference—83 points in AP Calculus BC—represents more than three-quarters of a standard deviation. Such large differences suggest that a score of 3

17. We would provide the same mean TIMSS Advanced scores for our non-AP groups, but since they have not taken an AP Exam, no scores are available.

or higher on AP Calculus and Physics Exams does indeed identify students achieving at a higher level than those students scoring below 3.[18]

In 2001, Gonzales and colleagues administered the 1995 TIMSS Advanced assessment to students taking AP Calculus and AP Physics courses. The researchers also found that students with scores of 3 or above on AP Exams performed at significantly higher levels on TIMSS Advanced compared to students scoring below 3 on AP Exams. Differences between the current study's methods, which follow TIMSS Advanced protocols, and those of Gonzales et al., make comparing results to the current study inappropriate. Only high school seniors participated in the current study; the Gonzalez sample included juniors, sophomores, and freshmen enrolled in AP. Students took only a single assessment in the current study, even if they were enrolled in both AP Calculus and AP Physics courses. In the Gonzales et al. study, students taking both AP Physics and AP Calculus courses were administered both TIMSS tests.

Table 31: Mean TIMSS Advanced Score by AP Score Groups < 3 or ≥ 3

	AP (Seniors Only)		
AP Test	**AP < 3**	**AP ≥ 3**	**Difference**
Calculus AB	427 (9.6)	547 (5.2)	120
Calculus BC	494 (9.9)	577 (6.8)	83
Physics 1	371 (11.1)	500 (8.6)	129
Physics C:M	428 (15.4)	534 (9.3)	106
Physics C:EM	501 (16.4)	603 (14.3)	102

Contexts of Learning

Student Preparation: Advanced Mathematics

Most schools prepare students for advanced mathematics through a sequence of course offerings. Some high schools offer an integrated option in which algebra, geometry, trigonometry, and calculus topics are taught in each course. Although, according to National Assessment of Educational Progress (NAEP) 12th-grade data and the survey data of the

18. One key question is whether AP Exam takers differ who are just above or below the cut point. How different are the TIMSS scores of AP students scoring 2 from students scoring 3? That question is outside the scope of the current study but may be investigated in follow-up work.

current study, enrollment in integrated courses never exceeds 5% in any 9–12 grade.[19] In the current study's school survey, school administrators were asked if schools had a special program or track that prepared students for advanced mathematics. Approximately two-thirds (67.0%) of U.S. students attended schools that had a program designed to prepare students for advanced mathematics.

When do most students take particular math courses? Consider the results from the latest federally funded longitudinal survey, the High School Longitudinal Study of 2009 (HSLS:09).[20] Researchers began collecting data on a nationally representative sample of more than 21,000 ninth graders in the fall of the 2009-10 school year. Periodic follow-up surveys were conducted, including one after the cohort's graduation in 2013, and a study of the sample's high school transcripts was completed that same year. As ninth graders, approximately 5.0% of the students enrolled in Algebra II, 20.5% in Geometry, and 48.7% in Algebra I. Starting with Algebra I, the common sequential approach to school mathematics in the United States requires four courses before enrolling in an AP Calculus course. Taking Geometry or Algebra II as high school freshmen can be considered the next segment of an accelerated pipeline leading to calculus no later than the senior year—and for some students, even earlier.[21]

Course Taking: Advanced Math Students

Table 32 summarizes the TIMSS Advanced students' reporting of the grades in which they completed mathematics courses. The most prominent grade-course combination for AP Calculus AB students is shaded. It also happens to match the course taking of non-AP Calculus students. Over 80% of AP Calculus AB and non-AP Calculus students completed Algebra I in Grade 8 or earlier. Over 70% completed Geometry in Grade 9, Algebra II in Grade 10, and Precalculus in Grade 11.

The AP Calculus BC group stands out as the most accelerated group. More than a third (36.1%) completed Geometry in eighth grade or earlier, almost half (45.9%) completed Algebra II in ninth grade, and almost half (45.3%) completed Precalculus as a high school sophomore. Over half of the AP Calculus BC group (58.6%) completed a calculus course in 11th grade, meaning that AP Calculus BC in 12th grade was the second year studying calculus for many of these students.

19. Brown, J., Schiller, K., Roey, S., Perkins, R., Schmidt, W., & Houang, R. (2013). The Nation's Report Card: Algebra I and Geometry Curricula--Results from the 2005 High School Transcript Mathematics Curriculum Study (NCES 2013-451). Washington, DC: National Center for Education Statistics.

20. Ingels, S.J., Pratt, D.J., Herget, D.R., Burns, L.J., Dever, J.A., Ottem, R., Rogers, J.E., Jin, Y., and Leinwand, S. (2011). High School Longitudinal Study of 2009 (HSLS:09). Base-Year Data File Documentation (NCES 2011-328). U.S. Department of Education. Washington, DC: National Center for Education Statistics. Retrieved from http://nces.ed.gov/pubsearch.

21. See Table E1 in U.S. Department of Education, National Center for Education Statistics, High School Longitudinal Study of 2009 (HSLS:09), Base-Year.

Table 32: Course Taking by Advanced Mathematics Students

Course	Grade in which completed	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Algebra I	Grade 8 or earlier	83.8 (3.2)	93.2 (1.6)	84.6 (2.3)
	Grade 9	14.2 (2.6)	5.6 (1.6)	10.3 (2.3)
Geometry	Grade 8 or earlier	7.0 (1.2)	36.1 (5.4)	11.1 (2.0)
	Grade 9	71.5 (3.5)	48.2 (6.0)	70.5 (3.7)
Algebra II	Grade 9	15.5 (2.8)	45.9 (5.4)	17.7 (4.4)
	Grade 10	75.2 (3.4)	43.4 (7.0)	74.2 (3.5)
Pre-Calculus (also called Introductory Analysis)	Grade 10	6.8 (1.6)	45.3 (5.7)	10.0 (2.4)
	Grade 11	85.8 (2.5)	40.8 (6.8)	75.9 (3.9)
Calculus	Grade 11	5.1 (1.3)	58.6 (6.1)	11.1 (2.9)
	Grade 12	94.5 (1.3)	83.5 (2.3)	79.9 (2.8)

Note: Table displays modal grade and adjacent grade of enrollment for each course. Modal grade for AP Calculus AB is shaded

Student Preparation: Advanced Physics

Student preparation in science varies widely depending on the state in which a student resides. High school graduation requirements, which in science are less standardized than math, account for much of this variation.[22] Some states require three years of science to receive a high school diploma, while other states require only two years, and in many cases the two or three courses are not the same. For example, to earn a Regents diploma in New York State, students are required to take three science courses, one Life Science, one Physical Science, and one additional Life or Physical Science.[23] In Illinois, only two science

22. http://www.ecs.org/high-school-graduation-requirements/

23. https://www.hesc.ny.gov/prepare-for-college/your-high-school-path-to-college/regents-requirements.html

courses are required, and the state does not mandate the type of science course required (e.g., biology, chemistry, physics, etc.). Illinois only provides a very broad statement regarding graduation requirements related to science, saying, "[i]n determining course offerings, school districts should provide the type of courses that will best meet the needs of their students as they pursue various work and study options after leaving high school."[24]

As a consequence of the variation in state requirements, the sequence of science courses that a student may take in high school is driven by a mix of district or school requirements, local resources, student schedules, and student interest. In the HSLS:09 sample, 34.0% of ninth graders enrolled in biology, 19.5% took a physical science course, and 12.4% enrolled in earth science. The curriculum of a 9th-grade physics or physical science course can be vastly different than a similar course offered at 11th grade, making it difficult to compare how each of these courses prepared the student for advanced-level science. Notably, only 1.7% of HSLS:09 students enrolled in chemistry as ninth graders, and more than one out of six (17.9%) took no science course at all in their freshmen year.[25]

In the current study, as was the case with advanced math, about two-thirds (69.3%) of administrators responding to the school survey indicated that their school had a special program or track to prepare students for advanced physics. Non-AP Physics students were more likely to attend such schools than their peers in AP groups. More than 8 out of 10 non-AP students (83.0%) attended a school with a special program or track, compared to 64.6% of students in AP Physics 1, 56.1% in AP Physics C:M, and 50.9% in AP Physics C:EM.

Table 33 indicates that most students in the current study take their first year of biology in either 9th or 10th grade. This is especially true for AP Physics C:M, (76.5%) and AP Physics C:EM (74.2%) students, suggesting that the more accelerated AP Physics students take a traditional biology, chemistry, physics course sequence. AP Physics C:M and AP Physics C:EM students are far more likely to take two years of physics, with 79.6% of AP Physics C:M students and 89.7% of AP Physics C:EM students taking second year physics in the senior year. Those figures compare to only 36.2% of non-AP Physics students and 46.7% of AP Physics 1 students.

Table 33: Course Taking by Advanced Physics Students

Course	Grade in which Completed	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Biology (first year)	Grade 9	53.5 (6.0)	76.5 (6.1)	74.2 (9.0)	48.1 (9.7)
	Grade 10	32.0	14.7	19.2	27.5

24. https://www.isbe.net/Documents/grad_require.pdf

25. Table E11 in U.S. Department of Education, National Center for Education Statistics, High School Longitudinal Study of 2009 (HSLS:09), Base-Year.

		(5.2)	(4.5)	(8.8)	(8.9)
Chemistry (first year)	Grade 10	59.0 (5.2)	77.9 (4.9)	74.0 (8.3)	60.9 (9.3)
	Grade 11	31.0 (5.1)	13.3 (4.4)	12.3 (6.8)	20.9 (6.4)
Physics (first year)	Grade 11	36.0 (5.6)	63.6 (6.8)	82.3 (5.2)	35.6 (9.6)
	Grade 12	49.4 (6.1)	17.3 (5.8)	4.3 (2.0)	34.9 (7.7)
Physics (second year)	Never	46.9 (5.5)	15.0 (5.7)	3.0 (1.9)	48.9 (8.7)
	Grade 12	46.7 (5.1)	79.6 (5.9)	89.7 (3.4)	36.2 (9.2)

Note: Exhibit displays modal grade and adjacent grade of enrollment for each course. The exception is second year physics, in which “never” was the next likely response, after “grade 12,” to taking a second year of physics. No row is shaded for second year physics because the “never” and “grade 12” percentages for the AP Physics 1 group does not reach statistical significance ($p<0.05$). Modal grade for AP Physics 1 is shaded.

AP student categories based on AP Exam taking. The category “non-AP” students excludes all students who took an AP course but did not take the AP Exam in 2015.

AP Calculus and AP Physics students differ as to the broader array of science courses available to the AP Physics student. Table 34 shows other AP science courses that students have either taken or were taking when they participated in TIMSS Advanced. AP Physics C:M and AP Physics C:EM students were far more likely to take another AP science course. Most notable is that 46.8% of AP Physics C:M and 45.6% of AP Physics C:EM students reported either that they had taken or were currently enrolled in an AP Chemistry course.

Table 34: AP Science Courses, Taken or Currently Taking

AP Course	AP Physics 1	AP Physics C: M	AP Physics C:EM	Non-AP Physics
Advanced Placement (AP) Biology	19.2 (3.1)	25.0 (3.8)	29.1 (4.9)	15.7 (4.2)
Advanced Placement (AP) Environmental Science	10.0 (2.3)	8.1 (1.6)	6.5 (2.7)	8.7 (2.6)
Advanced Placement (AP) Chemistry	28.6 (3.5)	46.8 (4.3)	45.6 (8.7)	17.2 (3.7)
Advanced Placement (AP) Physics	64.5 (2.9)	97.9 (1.0)	100.0 (0.0)	0.0 (0.0)
Advanced Placement (AP)	8.7	21.4	24.5	4.9

Computer Science A or AB	(1.6)	(3.7)	(5.4)	(1.5)

Technology

This section investigates the role technology plays in advanced mathematics and physics courses. Survey data from school administrators, teachers, and students address the potential impact of limited technological resources on instruction, the availability of support for using technology, how students use technology in calculus and physics classes, and the use of the internet in studying calculus.

Advanced Mathematics

Historically, mathematics as a school subject has had an interesting relationship with technology. Even though computer programming emerged out of mathematics departments as an applied field and other mathematics topics such as cryptography and numerical analysis use computers extensively, the use of technology in mathematics instruction has been limited to the use of scientific or graphing calculators. Over the past two decades, advanced mathematics courses in the United States have increasingly integrated the use of graphing calculators and many college entrance and national examinations in mathematics require the use of graphing calculators. It is within this context that we review survey responses to items that reveal the extent to which technology is available to teachers and students in mathematics classrooms.

Table 35: Calculus: School Technological Resources (General)

Is instruction at your school affected by a shortage or inadequacy of the following?	AP Students				Non-AP Students			
	Not at all	A little	Some	A lot	Not at all	A little	Some	A lot
Technologically competent staff	50.7 (4.2)	37.5 (4.0)	8.7 (2.0)	3.1 (1.6)	53.3 (8.3)	22.1 (5.2)	17.3 (6.6)	7.2 (4.5)
Audio visual resources	61.4 (4.8)	30.1 (4.3)	7.0 (1.7)	1.5 (0.9)	54.6 (10.9)	32.3 (10.3)	9.5 (2.5)	3.6 (2.9)
Computer technology for teaching	53.0 (5.2)	29.7 (4.2)	14.2 (3.2)	3.1 (1.1)	50.2 (9.2)	27.3 (7.5)	18.4 (5.9)	4.1 (2.8)

Note: Responses from school survey.

School administrators were asked to report whether resource shortages affected instruction at their schools. Table 35 displays responses related to technological resources. Over 80% of the students in the AP Calculus and 70% of the students in the non-AP Calculus groups were enrolled in schools where the administrator indicated “Not at all” or “A little.” Combining the "Some" and "A lot" response categories, however, suggests that there may small but noteworthy pockets of schools where shortages have an impact. Problems with acquiring a technologically competent staff was viewed by school administrators as affecting instruction "Some" or "A lot" for 11.8% of the students in the AP Calculus group and 24.5% of the non-AP-Calculus group. Similarly, 17.3% of the AP Calculus students and 22.5% of the non-AP group, approximately one-fifth of advanced mathematics students, were enrolled in schools in which a shortage or inadequacy of computer technology was viewed as affecting instruction "Some" or "A lot." These results should be taken only as suggestive since these items on the school survey did not specifically reference advanced mathematics and physics courses when responding to these items.

In terms of technology used specifically for mathematics instruction (Table 36), 13.8% of students in the AP Calculus and 12.7% of students in the non-AP Calculus group attended schools affected by a shortage of computer software "Some" or "A lot." With respect to a shortage or inadequacy of calculators, school administrators for 9.8% of students in the AP Calculus and 13.6% of students in the non-AP Calculus group indicated instruction was affected "Some" or "A lot."

Table 36: Calculus: School Technological Resources (Specific to Mathematics)

Is math instruction at your school affected by a shortage or inadequacy of the following?	AP Students				Non-AP Students			
	Not at all	A little	Some	A lot	Not at all	A little	Some	A lot
Computer Software/Application	48.3 (5.0)	38.0 (4.3)	10.3 (2.3)	3.5 (1.4)	53.5 (8.1)	33.8 (7.4)	11.8 (4.7)	0.9 (0.7)
Calculators	76.0 (3.1)	14.2 (2.8)	5.5 (2.0)	4.3 (1.4)	72.3 (7.1)	14.1 (5.8)	11.9 (4.9)	1.7 (1.1)

Note: Responses from school survey.

The teacher surveys also inquired about technology. When asked about the adequacy of technological resources, Table 37 shows that 11.1% of the students in AP Calculus groups had teachers reporting that a moderate or serious problem existed. A similar proportion of students had teachers who saw instructional materials and supplies as a problem (10.1 %). Only 4.0% of students in the non-AP group had teachers who felt access to technology was a moderate or serious problem, which was far less than the 14.1% of non-AP teachers who rated support for using technology as a moderate or serious problem.

Table 37: Calculus: Teacher Perceptions of Shortages in Current School

How severe is each problem?	AP Students				Non-AP Students			
	Not a problem	Minor problem	Moderate problem	Serious problem	Not a problem	Minor problem	Moderate problem	Serious problem
Teachers do not have adequate instructional materials and supplies	60.6 (5.0)	29.3 (4.1)	7.3 (2.0)	2.8 (1.3)	60.7 (11.1)	26.8 (7.9)	12.3 (7.6)	0.2 (0.1)
Teachers do not have adequate technological resources	57.9 (5.4)	30.9 (5.4)	8.0 (2.9)	3.1 (1.4)	57.3 (11.2)	38.7 (11.0)	2.2 (1.1)	1.8 (1.2)
Teachers do not have adequate support for using technology	50.5 (5.5)	30.5 (4.9)	15.5 (3.4)	3.5 (1.4)	46.8 (11.4)	39.1 (12.0)	12.3 (5.8)	1.8 (1.2)

Teachers were asked about their students' access to computers, tablets, calculators, or smart phones. Nearly all (92.6%) students in the AP Calculus group and the non-AP Calculus group (98.6%) had teachers who confirmed that students have access to at least one of these devices during advanced mathematics lessons. So, in spite of some administrators and teachers identifying access to technology as a problem on other survey items, student use of such devices is common.

Table 38 explores how technology is used. The most common use of technology was to draw graphs of functions, with 43.5% of students with teachers in the AP Calculus group and 41.1% of students with teachers in the non-AP Calculus group using technology in this way almost daily. In fact, over 90% of the AP Calculus group and close to 80% of the non-AP Calculus group uses technology to graph functions at least once a week. Contrast this with students' experience in the typical undergraduate calculus course in which only one-third of college students are allowed to use graphing calculators on course examinations.[26] As Bressoud (2015) concluded, "Permission to use graphing calculators on exams is one of the sharp discontinuities between high school and college calculus" (p. 10). Given the rapid comparisons that can be made with functions when using a graphing calculator, it is not surprising that this was the most popular use of technology in advanced mathematics high school classrooms. Students also use technology to perform numerical integration, with 38.8% of students in the AP Calculus group and over 25.8% of students in the non-AP Calculus group using technology in this way almost daily. In addition to these uses, over one-third of students in each group used technology almost daily to manipulate algebraic expressions.

26. See Table on page 9: http://www.maa.org/sites/default/files/pdf/cspcc/InsightsandRecommendations.pdf

Table 38: Calculus: Use of Technology During Advanced Mathematics Lessons

How often do you have the students do the following activities on computers, tablets, calculators, or smartphones?	AP Students				Non-AP Students			
	Every or almost every day	Once or twice a week	Once or twice a month	Never or almost never	Every or almost every day	Once or twice a week	Once or twice a month	Never or almost never
Read the textbook or course materials in digital format	15.8 (5.1)	17.8 (4.3)	6.4 (2.2)	60.0 (5.8)	18.8 (9.0)	8.4 (4.4)	8.0 (3.2)	64.7 (10.8)
Look up ideas and information	6.1 (2.1)	32.5 (6.0)	37.5 (3.9)	23.8 (5.4)	7.5 (4.8)	29.4 (10.2)	19.0 (6.0)	44.2 (12.0)
Process and analyze data	23.4 (4.7)	32.3 (4.9)	30.7 (5.6)	13.6 (4.1)	25.9 (9.9)	19.9 (5.9)	25.4 (9.6)	28.8 (11.0)
Draw graphs of functions	43.5 (5.5)	50.2 (5.7)	5.4 (2.0)	0.9 (0.5)	41.1 (9.1)	37.8 (8.3)	17.0 (11.7)	4.0 (3.8)
Manipulate algebraic expressions	41.5 (5.6)	24.5 (5.2)	13.3 (4.9)	20.7 (5.3)	33.0 (10.8)	25.9 (7.5)	14.4 (8.3)	26.6 (10.1)
Conduct modeling and simulations	19.7 (3.9)	22.9 (4.7)	39.2 (6.4)	18.2 (4.8)	9.5 (4.0)	15.2 (4.8)	37.7 (10.6)	37.5 (12.6)
Perform numerical integration	38.8 (4.6)	48.8 (4.5)	8.9 (2.6)	3.6 (1.8)	25.8 (7.4)	47.7 (9.0)	1.8 (1.2)	24.7 (11.5)

Students were asked the extent to which they used the internet in their advanced mathematics class. Responses to these questions demonstrate the extent to which technology permeates students' interactions with the organization and content of calculus courses (Table 39). Approximately three-quarters of the students in the AP Calculus group used the internet to find information or tutorials to help solve mathematics problems. The proliferation of instructional videos, applets, and discussion boards for mathematics provides students an abundance of resources to turn to when they struggle with solving homework problems—and many students use these resources. Many internet-based instructional resources are accessible on a smartphone. The ease of accessibility underscores that students must be informed users of websites, which often vary in quality or accuracy.

Students also use the internet to access information about the textbook or course assignments, communicate with teachers about assignments and course grades, and collaborate with other students. Close to half of students in both the AP Calculus and non-AP Calculus groups responded that they used the internet to support their course-related communication and access to information.

Table 39: Calculus: Student Use of Internet for Advanced Mathematics Schoolwork

Do you use the Internet to do any of the following tasks (including classroom tasks, homework, and studying outside of class)?	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Access the textbook or other course materials	48.0 (3.2)	60.0 (5.4)	42.0 (3.8)
Access assignments posted online by my teacher	56.6 (3.7)	55.7 (6.7)	48.3 (6.8)
Collaborate with classmates on mathematics assignments or projects	41.8 (2.4)	41 (4.3)	39.2 (3.6)
Communicate with the teacher	51.0 (2.5)	58.6 (3.5)	52.2 (3.3)
Discuss mathematics topics with other students	32.3 (2.0)	33.9 (5.5)	29.2 (2.7)
Find information, articles, or tutorials to aid in understanding mathematics concepts	72.7 (2.4)	79.1 (2.3)	58.2 (3.8)
Find information, articles, or tutorials to aid in solving mathematics problems	78.5 (2.5)	80 (3.0)	62.5 (3.2)

Technology: Advanced Physics

Technology and science are interdependent. As outlined in the Science College Board Standards for College Success (2009), College Board, “not only values students’ use of technology as a tool to practice science, but also believes it is essential for students to begin developing an understanding of the complex relationship among science, technology and society” (p. 19). This interdependence is critical for the advancement of both science and technology, as ongoing development of technology relies on the advancement of science, and progress in science depends on ever more advanced technologies to allow science to progress.

In advanced physics classes, most school administrators did not report shortages in technology as a significant barrier to providing instruction. As shown in Table 40, 88.9% of AP Physics students and 85.0% of non-AP students were enrolled in schools where administrators indicated that technologically competent staff was “Not at All” or only “A Little” problem. These same administrators also reported that adequate technology was available in their schools and that technology was not an issue that affected instruction. Only 4.5% of AP Physics students and 2.5% of non-AP Physics students were enrolled in schools where the administrator reported that inadequate computer technology was affecting instruction “A Lot.”

Table 40: Physics: School Technological Resources (General)

Is instruction at your school affected by a shortage or inadequacy of the following?	AP Students				Non-AP Students			
	Not at all	A little	Some	A lot	Not at all	A little	Some	A lot
Technologically competent staff	56.8 (5.4)	32.1 (5.2)	7.1 (2.4)	4.0 (2.3)	43.9 (10.2)	41.1 (9.9)	12.3 (6.4)	2.7 (1.4)
Audiovisual resources	59.8 (7.7)	31.5 (7.1)	6.7 (1.9)	2.0 (1.2)	39.2 (12.5)	41.6 (12.8)	18.3 (9.9)	0.9 (0.6)
Computer technology for teaching	47.0 (7.7)	30.9 (7.2)	17.6 (4.3)	4.5 (1.9)	32.7 (12.3)	36.7 (13.0)	28.0 (8.4)	2.5 (1.3)

Table 41: Physics: School Technological Resources (Specific to Physics)

Is physics instruction at your school affected by a shortage or inadequacy of the following?	AP Students				Non-AP Students			
	Not at all	A little	Some	A lot	Not at all	A little	Some	A lot
Computer Software/Application	47.8 (7.8)	36.5 (7.6)	11.6 (4.1)	4.0 (1.9)	34.0 (12.0)	47.1 (13.2)	15.2 (7.2)	3.6 (2.1)
Calculators	78.7 (4.3)	14.3 (3.7)	3.2 (1.8)	3.7 (1.7)	67.8 (10.3)	7.1 (3.7)	20.8 (10.7)	4.4 (2.2)

Physics teachers were asked similar questions, and their responses paint a similar picture. Shortages in technology do not appear to be a serious problem, as 84.3% of AP Physics students and 81.1% of non-AP Physics students had teachers who answered “Not at All” or “A Little” when asked if shortage or inadequacies in computer software/applications affected their physics instruction. It is also interesting to note that only 3.7% of AP Physics students and 4.4% of non-AP physics students had teachers that reported a shortage of calculators had affected their physics instruction “A Lot.” Advanced physics students are often expected to use technology to model, to graph, and to calculate while solving problems, and both teachers and administrators report that in all but a few schools this is not an issue.

There was one notable exception to the overall positive findings. Teachers were asked if they have adequate support for using technology: 17.2% of students in AP Physics had teachers that reported this was a “Serious Problem.” Interestingly, this only appears to be an issue for AP Physics teachers, as only 1.7% of non-AP students had teachers that reported support for using technology was a “Serious Problem.”

Table 42: Physics: Teacher Perceptions of Shortages in Current School

How severe is each problem?	AP Students				Non-AP Students			
	Not a problem	Minor problem	Moderate problem	Serious problem	Not a problem	Minor problem	Moderate problem	Serious problem
Teachers do not have adequate instructional materials and supplies	43.9 (6.7)	23.9 (5.1)	29.2 (4.6)	3.0 (2.0)	55.2 (13.2)	13.7 (4.7)	24.5 (12.6)	6.6 (5.6)
Teachers do not have adequate technological resources	49.8 (5.7)	19.2 (4.0)	16.2 (4.9)	14.9 (2.4)	47.7 (12.7)	36.9 (13.2)	12.9 (5.9)	2.5 (1.6)
Teachers do not have adequate support for using technology	46.6 (6.2)	25.3 (5.9)	11.0 (3.1)	17.2 (3.1)	54.3 (12.1)	29.2 (12.6)	14.8 (7.5	1.7 (1.2)

Teachers and Teaching

This section begins with a discussion of STEM teacher shortages. We then summarize the experience and qualifications of teachers of advanced mathematics and physics courses. The section concludes with an examination of teachers' confidence in teaching advanced mathematics and physics courses and the instructional challenges they may encounter.

Teacher shortages contribute to the problem of staffing schools with well-qualified teachers. Shortages in math and science have been a policy concern for at least the past two decades. As reported by Sutcher, Darling-Hammond, and Carver-Thomas (2016), as recent as the 2015-16 school year, "42 states and the District of Columbia reported shortages in mathematics [teachers]" (p. 5).[27] Shortages are not only concentrated in rural schools, but also in urban, high-poverty schools (NCES, 2014, 2016) and in some states more than others.[28] According to the national Schools and Staffing Survey (SASS), shortages of STEM teachers peaked in the 1999–2000 school year, affecting about one-third of schools. In 2011–2012, about 21% of schools reported difficulty filling STEM vacancies.[29]

Not all high schools offer advanced math and science courses. A 2016 analysis by *Education Week* illustrates the regional disparities in physics offerings. About 40% of U.S.

27. Sutcher, L., Darling-Hammond, L., & Carver-Thomas, D. (2016). *A Coming Crisis in Teaching? Teacher Supply, Demand, and Shortages in the US.* Retrieved from https://learningpolicyinstitute.org/product/solving-teacher-shortage

28. National Center for Education Statistics, The Condition of Education (Washington, D.C.: U.S. Department of Education, 2016) https://nces.ed.gov/programs/ coe/pdf/coe_slc.pdf

29. See Figure 3 in Cowan, Goldhaber, Hayes, and Theobald, "Missing Elements in the Discussion of Teacher Shortages (2016, American Institutes for Research).

high schools do not offer physics at all. Schools in rural areas are especially unlikely to provide physics courses, but a lot of variation exists among predominantly rural states. In Alaska and Oklahoma, the percentage soars to 70% of high schools not offering physics, but in Iowa, New Hampshire, and Maine, only 15% of high schools are without a physics course. More than being a uniquely rural problem, the lack of a physics course appears correlated with school size. The high schools offering physics enrolled an average of 880 students; those without physics averaged only 270 students.[30]

Advanced Mathematics

In the current study's advanced mathematics sample, survey data are consistent with the findings from SASS. When asked how much their school's capacity to provide instruction was affected by a shortage of teachers with subject-area specialization, about two-thirds of advanced students were in schools where the school administrator responded *not at all*. The response rates for the other options were: "a little" (24.2%), "some" (7.9%), and "a lot" (2.2%), and in advanced physics, "a little" (16.4%), "some" (13.9%), and "a lot" (3.6%).

Table 43: Calculus: Teachers' Experience

Started teaching	AP Calculus AB	AP Calculus BC	Non-AP Calculus
15 or more years ago	70.9 (5.7)	69.0 (8.8)	81.9 (6.0)
5–14 years ago	19.8 (4.5)	19.6 (7.0)	16.8 (5.9)
Less than 5 years ago	9.3 (4.4)	11.3 (6.4)	1.3 (1.1)

Note: AP student categories based on AP Exam taking. The category "Non-AP" students excludes all students who took an AP course but did not take the AP Exam in 2015.

Source: TIMSS Advanced 2015 teacher survey and College Board 2015 AP datafile.

Teachers who are assigned to teach advanced mathematics courses, such as calculus, typically have greater seniority relative to their colleagues in mathematics departments. Table 43 shows when the current study's teachers started teaching. For the two AP Calculus groups, approximately 70% of students had teachers who started teaching before 2000, 19.8% had teachers who started in 2001–2010, and 9.3% had teachers who started teaching after 2011. For the non-AP Calculus group, 81.9% of students had teachers who started teaching before 1970–2000, 16.8% had a teacher who started teaching in 2001–2010, and 1.3% had a teacher who had been teaching for less than five years when TIMSS Advanced was conducted in 2015. In general, teachers with the most teaching experience, over 15 years, taught most advanced mathematics students.

30. Liana Heitlin, "2 in 5 High Schools Don't Offer Physics, Analysis Finds," *Education Week*, August 23, 2016.

Table 44 summarizes the percentage of advanced mathematics students with teachers in five different age groups. As suggested in the previous discussion of years of experience, the largest age group for the AP Calculus AB group (39.6%) was the category “50 or more years.” For the non-AP Calculus group, 50.8% of students had teachers who were between 40 and 49 years, and 32.1% of students had teachers who were more than 50-years-old. Students rarely had an advanced mathematics teachers who was 29 years old or younger.

Table 44: Calculus: Teachers’ Age

How old are you?	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Under 25 years	1.8 (1.3)	3.8 (3.7)	1.1 (1.1)
25–29 years	9.5 (3.8)	6.7 (4.8)	4.9 (3.8)
30–39 years	18.0 (4.4)	21.4 (7.0)	11.2 (4.7)
40–49 years	31.1 (4.5)	36.1 (7.5)	50.8 (11.2)
50 or more years	39.6 (5.9)	32.0 (10.7)	32.1 (10.1)

In addition to an ongoing shortage of mathematics teachers, another concern among school administrators is the extent to which teachers are teaching in an area outside of their area of specialization. Table 45 shows the percentage of advanced mathematics students with teachers who majored in mathematics, physics, or mathematics or science education. For the AP Calculus AB group, at least 75% of the students had a teacher with a degree in mathematics or mathematics education (teachers who completed a major in mathematics and a licensure program in mathematics education may have selected both). For the AP Calculus BC group, 83.8% of students had a teacher who majored in mathematics, and for the non-AP Calculus group, 85.6% of students had a teacher who majored in mathematics. Approximately 10% of the AP Calculus AB and non-AP Calculus students had teachers who majored in physics.

Table 45: Calculus: Teachers’ College Major

What was your college major or main area(s) of study?	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Mathematics	77.1 (5.2)	83.8 (4.8)	85.6 (8.0)
Physics	10.1 (2.7)	7.6 (2.2)	12.6 (7.5)

Education—Mathematics	75.2 (4.3)	75.4 (6.5)	70.8 (12.4)
Education—Physics	1.1 (0.7)	3.5 (2.0)	2.5 (2.0)
Education—Science	0.9 (0.7)	0.6 (0.7)	5.4 (5.2)

Note: Respondents were allowed to select more than one major.

As shown in Table 46 the highest level of formal education completed by advanced mathematics teachers was most often a master's degree. For students of AP Calculus BC, 85% had teachers who earned a master's degree or beyond. In comparison, 70.1% of students of non-AP Calculus were taught by a math teacher with a master's degree and 69.2% of students in AP Calculus AB had teachers who earned a master's degree. Given that advanced mathematics teachers average over 15 years of teaching experience, one might expect that most of these teachers would have pursued a master's degree during that time to contribute to their own professional development.

Table 46: Calculus: Teachers' Highest Degree

Highest level of formal education completed	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Bachelor's degree	30.8 (6.0)	15.0 (5.7)	29.9 (10.5)
Master's degree or beyond	69.2 (6.0)	85.0 (5.7)	70.1 (10.5)

Teachers were also asked about their confidence with particular teaching activities (see Table 47). Two of the groups expressed the greatest confidence in assessing student comprehension of advanced mathematics. More than half (51%) the students in AP Calculus AB and 70.9% of students in non-AP Calculus had teachers reporting very high confidence in this classroom practice. The AP Calculus BC group had slightly higher confidence than the non-AP Calculus or AP Calculus AB groups in providing challenging tasks for the highest achieving students' interest, with 60.4% of students having a teacher with such high confidence. The activity in which advanced mathematics teachers said they had the least amount of confidence was improving the understanding of struggling students. For the AP Calculus AB group, only 30.5% of the students had teachers who indicated very high confidence in helping struggling students. In contrast, more than half (55.4%) of the non-AP Calculus group had students with teachers who indicated high confidence.

Recall that teachers of advanced mathematics courses, in general, had extensive teaching experience and most had completed a master's degree. Yet, finding ways to assist struggling students still remains a challenge for these teachers, even with students enrolled in the most advanced mathematics courses offered by the school. To some extent, this is a challenge that is at the heart of teaching any subject matter as it requires substantial knowledge of how students learn mathematics, content knowledge, and understanding of the needs of individual students.

Table 47: Calculus Teachers' Confidence in Teaching Activities

(Question: "In teaching advanced mathematics to this class, how would you characterize your confidence in doing the following?" Percentage responding "very high confidence")

Teaching Activity	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Providing challenging tasks for the highest achieving students' interest	49.3 (4.5)	60.4 (7.9)	59.2 (9.6)
Assessing student comprehension of advanced mathematics	51.0 (5.0)	53.1 (9.5)	70.9 (7.5)
Improving the understanding of struggling students.	30.5 (4.2)	46.6 (9.1)	55.4 (8.1)
Developing students' higher order thinking skills	45.1 (5.3)	57.8 (8.3)	49.9 (9.2)

Teachers and Teaching: Advanced Physics

As discussed above, there is a well-documented teacher shortage that exists in the United States for qualified physics teachers, particularly at the advanced level.[31] For the AP Physics 1 group, 31.3% of students had teachers who started teaching before 2000, 41.9% had teachers who started teaching from 2001–2010, and 26.8% had teachers with less than 5 years' experience when the 2015 AP and TIMSS Advanced exams were given. Teachers of the non-AP Physics group possess even more seniority; about half (49.8%) of the non-AP students had teachers who started teaching before 1970–2000, 35.0% had teachers who started teaching between 2001 and 2010, and 15.2% had teachers who began after 2011. Students in the AP Physics C:M and AP Physics C:EM groups were the least likely to be taught by beginning teachers. Only 5.0% of AP Physics C:M students and 5.4% of Physics C:EM students had teachers who began teaching after 2011.

Table 48: Physics: Teachers' Experience

What year did you start teaching?	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Before 1970—2000	31.3	51.0	58.1	49.8

31. American Association for Employment in Education, Educator Supply and Demand in the United States, AAEE, Columbus, OH (2005), available at http://www.aaee.org/pdf/2004fullreportforwebsite.pdf

	(7.9)	(9.0)	(11.3)	(14.5)
2001—2010	41.9	44.0	36.5	35.0
	(9.4)	(10.0)	(12.2)	(10.7)
After 2011	26.8	5.0	5.4	15.2
	(4.1)	(3.8)	(5.7)	(12.5)

These results are in line with the pattern observed above in math, that it is common to find teachers with the most teaching experience, over 15 years, teaching the most advanced physics classes. Table 49 reaffirms this finding by reporting the age of teachers of advanced physics. The number of teachers who are at least 50 years old serves as an indicator of retirements in the near future. Across the four physics groups, 20%–38% of students had teachers in that age group.

Table 49: Physics: Teachers' Age

How old are you?	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Under 25 years	1.9	2.0	0.0	0.2
	(1.4)	(2.3)	(0.0)	(0.2)
25–29 years	28.7	4.3	5.3	16.2
	(5.0)	(3.3)	(5.7)	(12.5)
30–39 years	14.5	35.3	25.3	13.3
	(3.9)	(8.9)	(10.5)	(4.7)
40–49 years	34.7	31.4	33.3	33.1
	(9.2)	(9.0)	(12.9)	(11.0)
50 or more years	20.1	27.1	36.0	37.3
	(7.1)	(7.7)	(11.4)	(14.8)

As shown in Table 50, AP students are more likely than non-AP students to be taught by a teacher who majored in physics. Almost 6 out of 10 (58.9%) AP Physics 1 students had teachers who were physics majors. For AP Physics C:M students, the figure was 53.7% and for AP Physics C:EM, it was 57.3%. About 38% of non-AP Physics students had a teacher who majored in physics. The overwhelming majority of AP Physics students, 80% or more, had teachers who had earned at least a master's degree (see Table 51). A little more than half (56.7%) of the non-AP group was taught by physics teachers with at least a master's degree.

Table 50: Physics: Teachers' College Major

What was your college major or main area(s) of study?	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Mathematics	36.0	20.2	27.0	27.7

	(7.2)	(6.8)	(8.7)	(14.5)
Physics	58.9	53.7	57.3	37.5
	(9.3)	(9.5)	(13.8)	(12.4)
Education–Mathematics	24.4	5.1	14.9	8.5
	(4.5)	(3.7)	(10.1)	(6.6)
Education–Physics	42.3	18.3	25.7	9.2
	(8.4)	(6.7)	(11.6)	(3.4)
Education–Science	34.9	11.3	13.5	14.0
	(7.4)	(5.5)	(8.5)	(4.5)

Note: Respondents were allowed to select more than one major.

Table 51: Physics: Teachers' Highest Degree

Highest level of formal education completed	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Bachelor's degree	9.8	18.4	16.2	43.3
	(3.4)	(7.0)	(4.1)	(14.4)
Master's degree or beyond	90.2	81.6	83.8	56.7
	(3.4)	(7.0)	(4.1)	(14.4)

The teachers were asked about their confidence in teaching. Table 52 displays the percentage of students with a teacher expressing "very high" confidence, the highest level of response, in several instructional activities. Noticeable differences exist between AP Physics teachers' and non-AP Physics teachers' level of confidence in three key areas. First, only 18.1% of non-AP students had a teacher with very high confidence in providing challenging tasks for high achievers. That compares with 29.5% of AP Physics 1 students, 35.5% of AP Physics C:M students, and 45.8% of AP Physics C: EM students. Similarly, non-AP students were unlikely (only 8.4%) to have a teacher expressing very high confidence in assessing student comprehension of advanced physics. All three groups of AP students had teachers with higher rates of confidence; in AP Physics 1 classes, for example, 34.9% of students were taught by an advanced physics teacher indicating very high confidence. Finally, only 18.5% of non-AP students had a teacher expressing the highest level of confidence in developing students' higher order thinking skills compared to at least a third of students in the AP groups—and about half (50.1%) of the AP Physics 1 students.

Table 52: Physics: Teachers' Confidence in Teaching Activities

(Question: "In teaching advanced physics to this class, how would you characterize your confidence in doing the following?" Percentage responding "very high confidence")

Activity	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Providing challenging tasks for the highest achieving students' interest	29.5 (7.8)	35.5 (8.7)	45.8 (13.4)	18.1 (7.3)
Assessing student comprehension of advanced physics	34.9 (7.4)	19.2 (6.5)	31.9 (12.8)	8.4 (3.5)
Improving the understanding of struggling students.	20.1 (8.5)	19.7 (7.0)	34.7 (9.9)	31.2 (14.5)
Developing students' higher order thinking skills	50.1 (7.9)	33.1 (8.3)	36.1 (12.7)	18.5 (7.6)
Teaching physics using inquiry methods	17.8 (5.6)	11.8 (5.1)	17.8 (10.2)	14.4 (6.8)

The responses to one question were particularly revealing in regard to teachers' more limited confidence in teaching physics using inquiry methods. Just 14.4% of students in the non-AP physics group and 11.8% to 17.8% of students in the AP Physics groups had teachers who described themselves as very highly confident using inquiry methods. Given the focus and effort devoted to encouraging inquiry methods in high school science classes, some speculation is warranted as to why these percentages are so small. It is possible that these teachers are very good at teaching inquiry methods but underestimate their ability to teach in this way. It is also possible that the term "inquiry methods" has come to mean a lot of different things, and teachers are unclear or unwilling to say that they are highly confident to teach physics using inquiry methods. Perhaps, too, history has a say here. As some pedagogical reformers have championed inquiry methods for more than a century—and have been inevitably disappointed in how little their efforts changed classroom instruction.

Student Aspirations and Attitudes

The groups sampled for this study represent students who completed the most advanced mathematics and science courses offered in high schools in the United States. Given the likelihood that a considerable proportion of these students may pursue STEM intensive fields, it is useful to examine their aspirations and attitudes toward mathematics, science, and school.

Advanced Mathematics

Students who enroll in Advanced Placement courses, and participate in the culminating AP Exams, are completing coursework equivalent to introductory college calculus. Students who score a 3 or higher on the AP Calculus Exam, depending on the institution, can earn college credit toward a bachelor's degree. This is one of the primary incentives for students to prepare for the end-of-course AP Exam. Given these incentives, and the relatively high achievement in mathematics of this group of students, it is expected that most of this group would aspire to pursue a college degree.

Table 53: Calculus: Educational Aspirations

Highest Expected Degree	AP Calculus AB	AP Calculus BC	Non-AP Calculus
High School	0.1 (0.1)	0.5 (0.5)	0.2 (0.1)
Associate degree (2-year college program)	0.2 (0.1)	0.1 (0.1)	0.5 (0.3)
Bachelor's degree (4-year college program)	25.2 (1.6)	19.8 (3.5)	30.2 (3.7)
Master's degree or professional degree (MD, DDS, lawyer, minister)	48.7 (2.1)	52.5 (2.8)	49.0 (3.8)
Doctorate (Ph.D., or Ed.D.)	25.8 (1.7)	27.0 (3.5)	20.2 (3.6)

As shown in Table 53, more than one-fourth (25.8%) of the students enrolled in AP Calculus AB intend to earn a doctorate and 48.7% intend to earn a master's or professional degree. Likewise, for AP Calculus BC, 27.0% plan on earning a doctorate and 52.5% plan to earn a master's or professional degree. That is, *over three-quarters* of high school students enrolled in AP Calculus courses not only intend to earn a bachelor's degree, they also plan on going to graduate school. The master's degree aspirations of the non-AP Calculus students are similar to that of the two AP groups (49.0%), but fewer (20.2%) plan on doctoral studies.

Students were also asked, *if you plan to continue your education, which area(s) do you intend to study?* For this prompt, students were instructed to check all areas that were of interest. The two most popular areas of study for both AP Calculus groups were Biomedical Science and Engineering. For the non-AP Calculus group, the two most popular areas were Biomedical Science and Arts and Humanities. Advanced mathematics students were also interested in mathematics or statistics as an area of study: 27.1% of AP Calculus AB, 30.8% of AP Calculus BC, and 19.8% of non-AP Calculus students expressed interest in this field. In general, AP Calculus AB and BC students were more interested in STEM disciplines as an area of study than fields such as business, law, or the social sciences.

Also, worth noting is the limited interest of all advanced mathematics groups in education. For the AP Calculus BC group, only 4.1% of the students expressed interest in education as a field of study. For the AP Calculus AB group, 6.9% of students were interested in education. For the non-AP Calculus group, 14.2% were interested in education as an area of study.

Table 54: Calculus: Intended Area of Postsecondary Study

Area of Study	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Mathematics or Statistics	27.1 (1.7)	30.8 (2.6)	19.8 (2.7)
Physics	13.7 (1.8)	23.9 (4.3)	13.4 (2.6)
Chemistry	13.4 (1.6)	18.1 (2.3)	13.7 (3.0)
Biological and Biomedical Science	35.5 (2.1)	34.7 (2.5)	30.8 (2.9)
Engineering and Engineering Technologies	29.4 (2.3)	37.4 (2.8)	17.0 (2.0)
Computer and Information Science	16.1 (2.1)	20.0 (3.7)	13.8 (1.8)
Education	6.9 (0.7)	4.1 (1.0)	14.2 (1.6)
Business	23.9 (1.6)	23.7 (4.0)	26.7 (3.1)
Law	8.5 (1.0)	7.6 (1.8)	7.4 (2.0)
Social Science	16.5 (1.6)	17.4 (3.0)	23.4 (3.3)
Arts and Humanities	16.4 (1.5)	19.9 (3.6)	26.9 (3.2)
Other Science Fields of Study	10.0 (1.2)	10.1 (2.3)	10.7 (1.3)
Other Non-science Fields of Study	6.8 (1.0)	10.3 (2.4)	7.7 (1.5)

Among the lay public in the United States, mentioning mathematics in conversation often provokes a negative emotional response, ranging from people who dismiss their own ability to engage in mathematical activity to those with an explicit dislike of the subject. Considering this context, the attitudes of students enrolled in advanced mathematics courses toward the discipline of mathematics is of interest. If any students might view mathematics favorably, it should be students pursuing mathematics at the highest level.

Table 55 summarizes students' attitudes toward studying mathematics. Students were asked the extent to which they agreed or disagreed with several statements. In general, the majority of students in all three groups agreed with the statement, *When I do mathematics problems, I sometimes get completely absorbed*. This prompt reflects both student persistence in problem solving and the sense of flow experienced when a challenge presented by a task is aligned with students' mathematical knowledge.[32] The AP Calculus BC group expressed the strongest agreement with this prompt (44.8% selected "Agree a lot"). The AP Calculus AB group (34.7%) had the next highest agreement, followed by the non-AP Calculus group (27.3%). The group responses to this prompt were similar to students' responses to, *mathematics is one of my favorite subjects*. All three groups had a majority of students who agreed with the statement. Of those who selected "Agree a lot," the AP Calculus BC group had the highest percentage (47.2%), followed by AP Calculus AB (41.1%), and then the non-AP Calculus group (26.2%). It is worth noting that, at the group level reported here, the psychological aspects of flow (i.e., getting completely absorbed in a math problem) seem to be correlated to viewing mathematics as a favorite subject.

In response to the prompt, *I feel bored when I do my mathematics schoolwork*, a plurality of students in all three groups agreed a little with the statement. The AP Calculus BC group had the largest percentage agreeing a little (46.3%), followed by AP Calculus AB (41.1%), and the non-AP Calculus group (39.7%). When combined with students who selected "Agree a lot," the majority of students in all three groups agreed that they feel bored when they do their mathematics schoolwork. In contrast to feeling bored, strong majorities of students in all three groups disagreed a little or a lot with the prompt, *I dread my mathematics class*. For AP Calculus BC, 80.1% disagreed with this statement (combining a little and a lot), followed by AP Calculus AB (71.2%) and non-AP Calculus (58.7%).

There was fairly strong disagreement across all three groups to the statement, *I wish I did not have to study mathematics*. For AP Calculus BC, 50.2% disagreed a lot; followed by AP Calculus AB (46.9%), and non-AP Calculus (34.4%). The statement, *learning advanced mathematics does not seem to be a worthwhile exercise* produced strong dissent, with "Disagree a lot" the modal response of both AP groups, AP Calculus AB (47.8%) and AP Calculus BC (57.8%). The modal response for the non-AP group was "Disagree a little" (43.6%).

Table 55: Calculus: Attitudes Toward Mathematics

How much do you agree with these statements about the mathematics you are studying?		**AP Calculus AB**	**AP Calculus BC**	**Non-AP Calculus**
When I do mathematics problems, I sometimes get completely absorbed	Agree a lot	34.7 (2.0)	44.8 (2.8)	27.3 (2.3)

32. Csikszentmihalyi, M. (1997). *Finding flow: The psychology of engagement with everyday life*. Basic Books.

	Agree a little	45.0 (1.9)	41.9 (2.8)	44.5 (3.6)
	Disagree a little	16.2 (1.3)	10.1 (2.5)	15.4 (1.8)
	Disagree a lot	4.1 (0.7)	3.2 (1.0)	12.7 (4.0)
I feel bored when I do my mathematics schoolwork	Agree a lot	13.8 (1.3)	11.7 (2.4)	27.6 (2.7)
	Agree a little	41.1 (2.0)	46.3 (3.4)	39.7 (2.0)
	Disagree a little	37.2 (1.8)	29.7 (4.2)	23.4 (2.0)
	Disagree a lot	7.8 (0.9)	12.3 (3.1)	9.3 (1.4)
I dread my mathematics class	Agree a lot	7.5 (0.7)	2.8 (0.8)	16.2 (2.1)
	Agree a little	21.3 (2.1)	17.0 (2.9)	25.1 (1.9)
	Disagree a little	36.0 (1.5)	35.0 (3.2)	28.2 (1.8)
	Disagree a lot	35.2 (2.0)	45.1 (3.6)	30.5 (3.1)
Mathematics is one of my favorite subjects	Agree a lot	41.1 (2.1)	47.2 (3.1)	26.2 (4.6)
	Agree a little	29.1 (1.6)	30.0 (2.9)	30.9 (4.3)
	Disagree a little	17.7 (1.9)	15.7 (2.7)	21.2 (2.9)
	Disagree a lot	12.2 (1.3)	7.2 (2.2)	21.7 (3.3)
I wish I did not have to study mathematics	Agree a lot	8.4 (1.7)	2.8 (0.8)	14.5 (1.8)
	Agree a little	15.4 (1.4)	12.6 (2.8)	23.4 (2.1)
	Disagree a little	29.3 (1.7)	34.4 (3.5)	27.7 (2.4)
	Disagree a lot	46.9	50.2	34.4

		(2.2)	(2.8)	(3.2)
Learning advanced mathematics does not seem to be a worthwhile exercise	Agree a lot	4.4 (0.8)	3.0 (0.9)	8.5 (1.6)
	Agree a little	11.3 (1.0)	14.0 (3.4)	18.8 (3.0)
	Disagree a little	36.5 (1.7)	25.2 (3.6)	43.6 (4.8)
	Disagree a lot	47.8 (1.9)	57.8 (3.0)	29.1 (2.6)

In sum, advanced mathematics students expressed positive attitudes toward school mathematics and mathematics as a discipline. Most of the students in all three groups feel that mathematics is a worthwhile subject and, in fact, indicated that it was one of their favorite subjects.

Table 56 summarizes students' impressions of the difficulty of the TIMSS Advanced Mathematics test compared to other tests they completed in school during the year. Sharp differences are evident among the groups. The majority of AP Calculus BC students (54.4%) felt that it was easier than other tests they completed. For the AP Calculus AB group, 42.5% responded that it was about as hard as other tests. In contrast, students in the non-AP Calculus group thought the TIMSS Advanced Mathematics test was harder (38.2%) or much harder (33.0%) than other tests. The contrasting responses suggest distinctive differences in the norms and expectations for each group in addition to differences in mathematical content.

Table 56: Advanced Math: Student-Reported Difficulty of the TIMSS Advanced Test

How hard was this test compared to most other tests you have taken this year in school?	AP Calculus AB	AP Calculus BC	Non-AP Calculus
Easier than other tests	23.3 (2.7)	54.4 (3.8)	7.3 (2.4)
About as hard as other tests	42.5 (2.2)	32.5 (2.6)	21.4 (1.9)
Harder than other tests	26.0 (1.9)	11.5 (2.2)	38.2 (3.2)
Much harder than other tests	8.2 (1.2)	1.6 (0.8)	33.0 (3.2)

Advanced Physics

The same incentives described above for AP Calculus students apply to AP Physics students. Chief among them is that an AP Physics student can earn college credit toward a bachelor's degree by scoring a 3 or better on any of the AP Physics assessments. Between 50%–55% of them expect to obtain a master's or professional degree in college. Interestingly, there is no discernable difference in the educational aspirations between the students that take an AP Physics course and the non-AP Physics students.

Table 57: Physics: Educational Aspirations

How far in your education do you expect to go?	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
High School	0.4 (0.3)	0.1 (0.1)	0.0 (0.0)	0.4 (0.7)
Associate degree (2-year college program)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.1 (1.9)
Bachelor's degree (4-year college program)	22.5 (2.8)	22.4 (2.9)	20.2 (3.7)	22.5 (2.2)
Master's degree or professional degree (MD, DDS, lawyer, minister)	52.9 (2.4)	53.0 (2.4)	55.4 (5.9)	52.9 (2.6)
Doctorate (Ph.D., or Ed.D.)	24.2 (1.6)	24.5 (2.7)	24.4 (6.6)	24.2 (3.5)

AP and non-AP Physics students have different plans when it comes to what these students intend to study in college. (Reminder: students were instructed to check all areas that were of interest.) AP students were much more likely to consider physics or engineering as a course of study than the non-AP Physics students: 41.6% of AP Physics C:EM and 33.0% of AP Physics C:M students choose physics compared to only 15.7% of non-AP Physics students. For the field of Engineering and Engineering Technologies, 66.0% of AP Physics C:EM and 59.9% of AP Physics C:M students considered that as a possible course of study compared to 28.1% of non-AP Physics students. The non-AP Physics students were more likely to choose Biological and Biomedical Science (33.1%), Social Science (21.8%), and Arts and Humanities (20.9%) than their AP counterparts.

As seen in the advanced mathematics group, there was limited interest by all of the advanced physics students for education as a course of study. Only 9.0% of non-AP Physics, 6.6% of AP Physics 1, 3.1% of AP Physics C:M, and 2.2% of AP Physics C:EM students planned on education as a future course of study. It is true, as noted in the mathematics section, that most physics teachers major in mathematics concurrent with (or prior to) enrollment in a licensure program; nevertheless, these numbers are very low and support the general conclusion that in the U.S. the most advanced science students do not plan to teach and are not interested in the formal study of education.

Table 58: Physics: Intended Area of Postsecondary Study

Area of Study	AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP Physics
Mathematics or Statistics	32.8 (3.2)	34.6 (4.7)	42.7 (6.4)	27.3 (5.4)
Physics	21.0 (1.5)	33.0 (5.2)	41.6 (6.3)	15.7 (4.8)
Chemistry	13.9 (1.7)	16.6 (2.6)	20.7 (3.7)	11.1 (1.6)
Biological and Biomedical Science	29.0 (1.8)	26.5 (2.8)	19.1 (5.0)	33.1 (2.6)
Engineering and Engineering Technologies	39.9 (2.3)	59.9 (2.8)	66.0 (4.6)	28.1 (4.9)
Computer and Information Science	22.4 (2.9)	27.2 (3.5)	34.2 (6.6)	19.0 (4.8)
Education	6.6 (1.9)	3.1 (1.2)	2.2 (1.3)	9.0 (2.0)
Business	25.0 (3.8)	17.3 (3.1)	24.1 (5.4)	27.6 (2.5)
Law	6.6 (1.0)	3.6 (1.1)	3.8 (3.4)	8.4 (2.0)
Social Science	14.2 (1.7)	7.1 (1.5)	12.5 (4.9)	21.8 (4.6)
Arts and Humanities	14.1 (1.4)	11.2 (2.1)	15.8 (3.5)	20.9 (3.4)
Other Science Fields of Study	11.2 (1.4)	5.8 (1.4)	13.3 (4.8)	11.3 (2.0)
Other Non-science Fields of Study	5.2 (0.8)	2.0 (0.9)	7.2 (3.6)	11.9 (1.1)

Students were also given several statements that elicited their overall attitudes toward physics. As one might expect, this group of advanced physics students had generally positive attitudes toward physics, although there are several notable differences between AP Physics students and non-AP Physics students (see Table 59).

Presented with the statement, *it is interesting to learn physics laws and principles*, 57.0% of AP Physics C:EM students agreed a lot while only 23.1% of non-AP students responded that positively. AP Physics 1 (36.8%) and AP Physics C:M (41.8%) students also displayed positive feelings toward the statement. Similarly, students were given the statement, *I enjoy figuring out challenging physics*, and 70.6% of AP Physics C:EM, 52.4% of AP Physics C:M, 36.4% of Physics 1, and 29.6% of non-AP Physics students agreed a lot. It is clear that AP Physics C:M and AP Physics C:EM students have the most positive attitudes toward physics and express an enjoyment in tackling the challenges of the subject much more so than their non-AP counterparts.

Table 59: Physics: Attitudes Toward Physics

How much do you agree with these statements about the physics you are studying?		AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP
It is interesting to learn physics laws and principles	Agree a lot	36.8 (2.4)	41.8 (5.0)	57.0 (6.2)	23.1 (7.1)
	Agree a little	41.1 (2.8)	42.2 (3.6)	35.4 (5.4)	38.8 (3.3)
	Disagree a little	16.4 (2.0)	11.3 (2.6)	6.9 (2.6)	22.7 (3.6)
	Disagree a lot	5.7 (1.2)	4.7 (2.3)	0.6 (0.5)	15.5 (3.7)
I dread my physics class	Agree a lot	10.7 (2.3)	7.4 (1.8)	7.1 (2.7)	16.7 (2.5)
	Agree a little	24.1 (2.6)	20.7 (3.4)	10.0 (2.8)	25.7 (4.2)
	Disagree a little	37.0 (2.8)	31.3 (3.1)	22.3 (3.2)	30.9 (2.4)
	Disagree a lot	28.3 (3.3)	40.5 (4.3)	60.6 (5.6)	26.7 (3.9)
I enjoy figuring out challenging physics	Agree a lot	36.4 (2.2)	52.4 (5.0)	70.6 (5.3)	29.6 (5.3)
	Agree a little	40.7 (2.0)	32.7 (2.1)	22.1 (4.3)	38.5 (2.7)
	Disagree a little	17.5 (1.9)	11.6 (3.5)	6.3 (1.9)	19.5 (3.9)
	Disagree a lot	5.4 (1.2)	3.3 (1.3)	1.1 (0.6)	12.4 (2.6)
Physics is one of my favorite subjects	Agree a lot	19.1 (2.3)	39.0 (5.2)	54.5 (5.8)	16.3 (4.2)

	Agree a little	27.9 (3.0)	30.1 (2.4)	26.8 (3.9)	21.3 (2.5)
	Disagree a little	29.7 (1.8)	20.6 (2.5)	12.5 (3.5)	26.5 (2.8)
	Disagree a lot	23.3 (3.2)	10.3 (3.1)	6.2 (2.2)	35.9 (4.5)

The positive feelings of the two advanced AP Physics groups is also evident in students' responses to the prompt, *physics is one of my favorite subjects*, with 54.5% of AP Physics C:EM and 39.0% of AP Physics C:M students agreeing a lot with the statement. The divergence of the other two groups becomes clearer in response to this prompt. Only 19.1% of AP Physics 1 and 16.3% of non-AP Physics students agreed a lot that physics was a favorite subject and, in fact, more than half of AP Physics 1 students (53.0%) and non-AP students (52.4%) disagreed a little or a lot.

Table 60 indicates that some of the group differences in attitudes may be associated with how useful students consider their advanced physics courses. AP Physics C:EM students were more than twice as likely to agree a lot with the statement, *learning physics will help me get ahead in the world*, than their non-AP peers. AP Physics C:EM students were also almost three times more likely to disagree a lot with the statement, *the physics I am studying is not useful for my future*, than non-AP physics students. Further, 72.7% of AP Physics C:EM, 57.3% of Physics C:M, and 45.6% of Physics 1 students, compared to 34.1% of non-AP Physics students agreed a lot that *doing well in physics will help me get into the college or university of my choice*. All three groups of AP Physics students were far more likely to agree a lot to the prompt: *learning physics will give me more job opportunities*. All of this reinforces the idea that AP Physics students see the content that they are learning as relevant to their overall career goals and future aspirations.

Table 60: Physics: Valuing the Study of Physics

How much do you agree with these statements about the physics you are studying?		AP Physics 1	AP Physics C:M	AP Physics C:EM	Non-AP
Learning physics will help me get ahead in the world	Agree a lot	43.4 (2.1)	51.3 (3.9)	64.7 (5.8)	27.6 (2.3)
	Agree a little	40.3 (2.8)	37.4 (2.5)	30.6 (6.0)	46.9 (2.3)
	Disagree a little	13.7 (1.5)	8.6 (2.1)	4.7 (1.7)	18.1 (2.3)
	Disagree a lot	2.7 (0.9)	2.7 (0.9)	0 (0.0)	7.4 (1.7)

The physics I am studying is not useful for my future	Agree a lot	8.7 (1.7)	4.9 (1.1)	2.7 (1.5)	11.6 (2.2)
	Agree a little	19 (1.7)	15.2 (3.3)	7.8 (2.5)	27 (2.2)
	Disagree a little	40.1 (2.1)	35.9 (2.9)	29.8 (6.3)	39.1 (2.5)
	Disagree a lot	32.2 (2.7)	44 (3.6)	59.6 (6.1)	22.3 (1.9)
Doing well in physics will help me get into the college or university of my choice	Agree a lot	45.6 (2.0)	57.3 (3.2)	72.7 (4.6)	34.1 (2.3)
	Agree a little	33.3 (2.3)	29.2 (2.6)	22.6 (4.5)	41.8 (3.7)
	Disagree a little	15.8 (1.7)	10.9 (1.6)	4.0 (1.8)	15.6 (2.6)
	Disagree a lot	5.3 (1.6)	2.6 (0.8)	0.8 (0.6)	8.5 (2.1)
Learning physics will give me more job opportunities	Agree a lot	42.8 (3.4)	54.0 (4.4)	73.1 (4.7)	24.0 (3.7)
	Agree a little	36.8 (3.5)	34.4 (2.9)	17.6 (3.9)	44.6 (3.3)
	Disagree a little	14.8 (1.5)	9.9 (2.1)	7.9 (2.9)	23.7 (3.2)
	Disagree a lot	5.6 (1.1)	1.7 (0.8)	1.4 (0.8)	7.7 (1.5)

Implications for Research and Policy

This study examines student performance on the TIMSS Advanced exams for groups of students who were enrolled in Advanced Placement Calculus and Physics courses, and other advanced mathematics and science courses. The survey responses from students, teachers, and school administrators addressed a number of pertinent factors related to the opportunity to learn advanced mathematics and science in the United States, as compared to other participating countries. This report also summarized the characteristics, attitudes, and aspirations of students who complete Advanced Placement Calculus and Physics, their teachers' background, and teachers' confidence and challenges in teaching these courses.

In this section, we elaborate further on the opportunity to learn advanced mathematics and science in the United States, and the related patterns in course taking organized by secondary schools. Student performance across content domains and dimensions of cognitive demand are discussed with respect to recent U.S. education policy in mathematics and science education. We also found students' attitudes toward these advanced courses, and their commitment to coursework, both in and out of class, to be noteworthy. The increased role and use of technology in advanced mathematics and science courses are unprecedented, especially when compared to the contexts for learning in undergraduate mathematics, and we elaborate further on the implications of this use of technology-based instructional resources in U.S. high schools. Lastly, the future challenge of sustaining and improving student performance in mathematics and science education relies on teachers. Given the experience and the age of teachers who teach advanced mathematics and science the United States, we discuss the implications for policy in teacher recruitment, preparation, and induction.

Opportunity to Learn

In the United States, more high school students are taking AP Calculus and AP Physics Exams than ever before. In the *2014 AP Report to the Nation* over 300,000 students took AP Calculus Exams, and over 100,000 students took AP Physics Exams.[33] When compared with exam participation rates in 2003, this represents an increase in participation in AP Calculus of over 75%, and an increase in AP Physics of 85%. In short, student access to and completion of advanced coursework in mathematics and science is not only at an all-time high in the United States, the increase in student demand for these courses reflects a trend that is promising with respect to student preparation for STEM majors and careers.

In addition, there is clear evidence from the *2014 AP Report to the Nation* that low-income students' access to AP courses has increased significantly over the past 10 years. These data show that even as AP participation rates have significantly increased, the overall AP test scores have remained stable, and in some instances increased. This would suggest that increasing student access to advanced level coursework does not require sacrificing the rigor of the coursework offered. Further, it is encouraging that the population of students participating has become more diverse and the overall AP Exam scores have remained stable. Additional evidence of this can be found in the TIMSS trend data, which supports this overall conclusion. As stated in section 4, the TIMSS Advanced coverage index for math and physics has nearly doubled, from 6.4% to 11.4% for math and from 2.7% to 4.8% for physics, from 1995 to 2015. Over this same timeframe there is no statistically significant difference in TIMSS Advanced performance results for U.S. students. This is an important finding, one that warrants more attention given that the U.S. was the only participating country to both increase student access of advanced level coursework without seeing a decline in performance results.

Another way that opportunity to learn may be affected is through content coverage and cognitive demand. Not all advanced math and physics classes study the exact same topics

33. https://secure-media.collegeboard.org/digitalServices/pdf/ap/rtn/10th-annual/10th-annual-ap-report-to-the-nation-single-page.pdf

or place identical cognitive demands on students. If students have not had an opportunity to learn mathematics or science topics, certainly their chance of responding correctly to a relevant test item is reduced. Similarly, students who have not been asked to know, to apply, or to reason rigorously during classroom instruction cannot be expected to demonstrate such skills with sophistication.

A study of TIMSS 1995 national-level data found that content coverage was significantly correlated with the percentage of items answered correctly, explaining between 25% and 50% of the between-country variance (Angell et al. 2006). In section 4, we reported that calculus was the strongest content domain for all of the study's analytical groups, with weaker showings in algebra and geometry. That distribution makes sense considering that U.S. students were enrolled in a calculus course when they took TIMSS Advanced, having completed courses in algebra and geometry in previous years. Physics students (with Physics C:EM students the exception) scored weakest on electricity and magnetism. A question demanding further research is whether these relative strengths and weaknesses matter for success in college. If America's top math and science seniors are graduating from high school needing review of material taught in earlier grades, and the forgotten material may negatively affect success in college, K–12 math and science educators would benefit from knowing this.

Performance of calculus students appeared balanced across TIMSS Advanced cognitive domains. In physics, applying was generally the weakest area for U.S. students. For AP Physics 1, the performance difference between applying (392) and reasoning (436) was statistically significant. Recent changes in the AP Physics curriculum have emphasized reasoning, which may partially explain these numbers. Cognitive domains have only recently begun to receive attention in international assessments. A question demanding more high quality research is whether there is an optimal balance of knowing, applying, and reasoning in a yearlong advanced mathematics or science course and whether particular topics benefit from stressing one domain over the others.

Student Attitudes

As reported in section 5, advanced students in math and science express positive feelings toward mathematics and physics. They have high aspirations for earning advanced degrees after high school. Many would like to study STEM topics in college and intend to enter professional careers that draw on mathematics and science. They also generally express enjoyment with studying mathematics and physics; however, responses to one prompt from the physics student questionnaire deserve scrutiny. In response to the statement, *physics is one of my favorite subjects*, more than half of non-AP Physics students said they disagree either a little (26.5%) or a lot (35.9%). A majority of AP Physics 1 students expressed similar sentiments (29.7% disagreed a little and 23.3% disagreed a lot).

As noted in the introduction, the relationship between student attitudes and learning isn't always clear cut. Myriad factors can influence students' selection of favorite school subjects, and it may be particularly difficult for some adolescents to develop positive views toward challenging coursework. Again, we underscore that the overall picture of student attitudes and aspirations is positive. Nevertheless, we wish to convey to teachers and principals of advanced students that, despite these students' high achievement, their contentment with math and science classes cannot be taken for granted.

Time Differences

In section 4, we found that in comparison to non-AP students AP students devote more time to mathematics and science in and out of school. For total time spent each week on math, AP Calculus BC students estimated 8 hours, 10 minutes; AP Calculus AB students estimated 7 hours, 37 minutes; and non-AP Calculus students estimated 5 hours, 32 minutes. The shortfall for non-AP students—at least two hours per week compared to Calculus AB students and over two and one-half hours compared to Calculus BC—is best appreciated when aggregated over a standard school year of 36 weeks. The data suggest AP students spend 72–90 more hours engaged with calculus and physics than their non-AP counterparts.

That is a substantial amount of time. The main cause of the discrepancy cannot be determined from the data, but student choice in selecting classes (some may have elected to take two physics or calculus classes concurrently), along with individual preferences about how to spend out of school time, is one possible explanation.

Students who struggle with calculus or physics should be encouraged to spend more time on these subjects. The matter need not be left solely to student discretion. One policy intervention that shows promise is known as "double dosing." Cortes, Goodman, and Nomi studied a Chicago program that assigned low-skilled ninth graders to two periods of algebra. Employing a regression discontinuity design that allows for causal inferences, the researchers found that the program significantly boosted ninth grade test scores and credits earned.[34] More importantly, the researchers followed the students through the remainder of their high school careers and discovered significant long-term effects, including higher graduation and college enrollment rates. Educators of advanced students, especially of students for whom advanced courses may be difficult, should investigate double-dosing as a scheduling option.

Technology

In this study, we found that technology use is somewhat ubiquitous in high school calculus and physics courses in the United States. Graphing calculators and Internet browser-based software are used by students to graph functions, solve equations, manipulate algebraic expressions, and run simulations. In spite of the current use of technology in AP Calculus

34. Kalena Cortes, Joshua Goodman, and Takako Nomi (2013). "Intensive Math Instruction and Educational Attainment: Long-Run Impact of Double-Dose Algebra," Harvard Kennedy School Faculty Research Working Paper Series, RWP13-09.

and AP Physics, teachers have limited access to professional development that supports the use of technology in these courses (Lawless and Pellegrino 2007). Most school administrators report that AP Calculus teachers have access to and support for the use of technology, although access to technology appears to be a moderate or serious problem for students of almost one-third of AP Physics teachers in this sample. We would argue that teacher and student use of technology in high school calculus and physics is one of the most crucial shifts in the use of instructional resources in these courses over the past 20 years. These findings suggest the need for additional research on how teachers can best use technology in instruction in mathematics and science.

In the United States, when comparing high school calculus to undergraduate calculus technology use also represents a major difference in the use of instructional resources. Technology is used weekly in high school calculus, but it’s rarely used in postsecondary calculus instruction. Even though these differences have been noted by Bressoud (2015) and in other studies of postsecondary calculus, there appears to be little movement toward greater use of technology in undergraduate mathematics departments, with the exception of using online homework tools (e.g., WebAssign) and student use of internet-based instructional videos outside of class. These differences in the use of technology in physics instruction in high schools and colleges are not as pronounced as they are for calculus. Even though education policy does not typically influence undergraduate instruction, a research agenda that explicitly investigates the ways in which technology might support active learning could be promoted (Freeman et. al. 2014).

For AP Calculus and AP Physics students, the prevalence of instructional videos, simulations, and applets provides a relatively new resource to turn to when students are uncertain about concepts and skills. Most of these resources are available at no cost to students (and these same resources are available to students outside the United States). This study offers a brief glimpse into students’ self-directed use of supplementary instructional resources: recall, four-fifths of AP Calculus and AP Physics students reported using the internet-based instructional resources. At present, this is an underreported area of research, both in the extent of student use of these resources as a supplement to face-to-face instruction in advanced mathematics and science, and in their relative impact on student learning and engagement. To fully understand the affordances and constraints of these resources, a more robust research agenda should be articulated and supported to understand how students use technology on their own to enhance their learning and achievement in mathematics and science. In addition, future large scale assessments could include questionnaires with a more comprehensive set of prompts specifically developed to focus on the goals, use, and challenges of instructional technology.

Teachers and Teaching

The calculus and physics teachers in this study share similar characteristics. They are older, more experienced, and most have earned a master’s degree. Approximately 70% of calculus students and 50% of physics students had teachers who had been teaching before

2000, with about one-third of AP and non-AP teachers nearing retirement age. The relative seniority of teachers, combined with recent flat or declining enrollments in secondary math and science programs, and higher turnover rates for novice teachers, should raise concerns for the future preparation of students who are pursuing STEM intensive college and career pathways. In addition, secondary mathematics and science tends to have higher turnover rates than their counterparts (Ingersoll et.al. 2014). These issues related to the teacher education pipeline for mathematics and science education have been known for years. Furthermore, Ingersoll, Merrill, and Stuckey (2014) also noted that

> … while these trends raise important questions, until recently we have seen little awareness or discussion of them or their implications—whether by researchers, by policymakers, by educators, or by the public … if these trends do indeed continue, there will be large implications, with serious financial, structural, and educational consequences for America's educational system (p. 27).

Well prepared, highly qualified teachers are critical to ensuring students' opportunity to learn, and their pursuit of STEM majors and careers. So, we reiterate the need for policymakers, and the public, to give attention to the need to improve the recruitment and retention of secondary mathematics and science teachers. As noted in section 5, advanced math and physics students have limited interest in education, which suggests that the teaching profession has an image problem among the next generation of math and science majors. This negative image is often reinforced by faculty, peers, and media when mathematics and science majors are encouraged to pursue more lucrative or prestigious options. However, recruitment is only part of the puzzle.

Some of the top reasons teachers give for leaving the profession include working conditions, lack of opportunity for professional growth, and input into decision making. Most of the teachers in this study had extensive teaching experience and most had completed a master's degree. Yet, finding ways to assist struggling students is reported to be a challenge by these teachers, even with students who have a strong interest in these courses. Likewise, less than one-fifth of students enrolled in physics had teachers who described themselves as very highly confident using inquiry methods. In almost any other industry or profession, such difficulty hiring and retaining enough qualified employees to meet the demands of the market would bring about a swift response; the political will to improve recruitment, retention, and work conditions would be strong. Leadership needs to emerge to communicate and implement a vision of attractive schools—and to enact policies that support effective induction experiences for candidates eager to develop professional knowledge and instructional practice.

Bibliography/References

Angell, C., Kjaernsli, M., and Lie, S. (2006). Curricular effects in patterns of student responses to TIMSS science items. In S. J. Howie & T. Plomp (Eds.), Contexts of learning mathematics and science (pp. 277–290). London: Routledge.

Baker, B. D. (2016). Does Money Matter in Education? Washington, DC: Albert Shaker Institute.

Beal, S. J. and Crocket, L. J. (2010). Adolescents' occupational and educational aspirations and expectations: Links to high school activities and adult educational attainment. *Developmental Psychology, 46*, 258–265.

Blank, R. K. and de las Alas, N. (2009). Meta Analysis Study of the Effects of Teacher Professional Development with A Math or Science Content Focus on Improving Teaching and Learning. Washington, DC: Council of Chief State School Officers.

Blosser, P. E. (1990). The role of the laboratory in science teaching. (NARST No 9001). Reston, VA: National Association for Research in Science Teaching.

Boghai, D. M. (1979). A comparison of the effects of laboratory and discussion sequences on learning college chemistry. *Dissertation Abstracts, 39*, 6045A.

Boser, U., Wilhelm, M., and Hanna, R. (2014). The power of the Pygmalion Effect: Teachers expectations strongly predict college completion. *Center for American Progress.* Retrieved from https://www.americanprogress.org/issues/education/report/2014/10/06/96806/the-power-of-the-pygmalion-effect/.

Bozick, R., and Ingels, S.J. (2008). Mathematics Coursetaking and Achievement at the End of High School: Evidence from the Education Longitudinal Study of 2002 (ELS:2002) (NCES 2008-319). National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC.

Cochran-Smith, M., and Lytle, S. L. (1999). Relationships of knowledge and practice: Teacher learning in communities. In A. Iran-Nejar, and P. D. Pearson (Eds.), *Reviews of research in education* (pp. 249-305). Washington, DC: AERA.

Comber, L. C. & Keeves, J. P. (1978). *Science education in nineteen countries, international studies in evaluation I*. New York: John Wiley & Sons, Inc.

CompTIA. (2011). IT opportunities in the education market. CompTIA. Retrieved from https://www.comptia.org/resources/it-opportunities-in-the-education-market.

Englert, C. S., and Tarrant, K. L. (1995). Creating collaborative cultures for educational change. *Remedial and Special Education, 16*, 325-336, 353.

Farkas, S. & Duffett, A. (2008). Part 2: Results from a national teacher survey. In *High-achieving students in the era of NCLB* (49-74). Washington DC: Thomas B. Fordham Foundation & Institute.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., and Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410–8415.

Floden, R. E. (2002). The Measurement of opportunity to learn. In A. C. Porter & A. Gamoran (Eds.) *Methodological Advances in Cross-National Surveys of Educational Achievement* (pp. 229-266). Washington, DC: National Academy Press.

Goddard, R. D., Hoy, W. K., and Hoy, A. W. (2000). Collective teacher efficacy: Its meaning, measure, and impact on student achievement. *American Educational Research Journal, 37*, 479-507.

Gregory, A., and Weinstein, R. S. (2004). Connection and regulation at home and in school predicting growth in achievement for adolescents. *Journal of Adolescent Research, 19*(4), 405–427.

Greenwald, R., Hedges, L. V., and Laine, R. D. (1996). The effect of school resources on student achievement. *Review of Educational Research, 66*, 361–396.

Grozier, J. E. Jr. (1969). The role of the laboratory in developing positive attitudes toward science in a college general education science course for nonscientist. *Dissertation Abstracts, 31*, 2394A.

Hanushek, E. A. (1994). Money might matter somewhere: A response to Hedges, Laine, and Greenwald. *Educational Researcher, 23*, 5–8.

Hedges, L. V., Laine, R. D., and Greenwald, R. (1994). An exchange: Part I: Does money matter? A meta-analysis of studies of the effects of differential school inputs on student outcomes. *Educational Researcher, 23*, 5–14.

Hess, F. M. (2014). America's future depends on gifted students. Retrieved from http://www.nytimes.com/roomfordebate/2014/06/03/are-new-york-citys-gifted-classrooms-useful-or-harmful/americas-future-depends-on-gifted-students.

Hoxby, C. (2000). Peer effects in the classroom: Learning from gender and race variation. (NBER Working Paper No. 7867). Cambridge, MA: National Bureau of Economic Research.

Ingersoll, R., Merrill, L., and Stuckey, D. (2014). Seven trends: the transformation of the teaching force, updated April 2014. CPRE Report (#RR-80). Philadelphia: Consortium for Policy Research in Education, University of Pennsylvania

Jeynes, W. H. (2005). A meta-analysis of the relation of parental involvement to urban elementary school student academic achievement. *Urban Education, 40*, 237-269.

Khattab, N. (2015). Students' aspirations, expectations, and school achievement: What really matters?" *British Educational Research Journal, 41*, 731-748.

Lawless, K. A., and Pellegrino, J. W. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. Review of Educational Research, 77(4), 575-614.

Leow, C., Marcus, S., Zanutto, E., and Boruch, R. (2004). Effects of advanced course-taking on math and science achievement: Addressing selection bias using propensity scores. *American Journal of Evaluation, 25*, 461-478.

Loveless, T. (2014, February 19). What do we know about professional development? Retrieved from http://educationnext.org/what-do-we-know-about-professional-development/.

Lytle, R. (2011, June 14). Study: Emerging technology has positive impact in classroom. Retrieved from http://www.usnews.com/education/high-schools/articles/2011/07/14/study-emerging-technology-has-positive-impact-in-classroom.

Miles, K. H., Odden, A., Fermanich, M., and Archibald, S. (2004). Inside the black box of school district spending on professional development: Lessons from five Urban Districts. *Journal of Education Finance, 30*, 1–26.

Mindich, D., and Lieberman, A. (2012). *Building a Learning Community: A Tale of Two Schools*. Stanford, CA. Stanford Center for Opportunity Policy in Education.

Mo, Y., Singh, K. and Chang, M. (2013). Opportunity to learn and student engagement: A HLM study on eighth grade science achievement. *Educational Research Policy and Practice, 12*, 3–19.

NEA. (2008). Technology in Schools: The Ongoing Challenge of Access, Adequacy, and Equity. (NEA Policy Brief). Washington, DC: NEA Educational Policy and Practice Department.

Plucker, J. (2014). We need to work together to make the common core work for gifted students. Retrieved from https://www.nagc.org/blog/we-need-work-together-make-common-core-work-gifted-students.

Rosenthal, R. & Jacobson, L. (1968). *Pygmalion in the classroom*. New York: Holt, Rinehart & Winston.

Ross, J. A. (1992). Teacher efficacy and the effects of coaching on student achievement. *Canadian Journal of Education, 17*, 51–65.

Sacerdote, B. (2014). Experimental and quasi-experimental analysis of peer effects: Two steps forward?" *Annual Review of Economics, 6*, 253–272.

Schmidt, W. H., McKnight, C. C., & Raizen, S. (1997). A splintered vision: An investigation of U.S. science and mathematics education. Dordrecht, NL: Kluwer.

Supovitz, J. A. (2002). Developing communities of instructional practice. *Teachers College Record, 104*, 1591–1626.

Torsten, Husen, (1967). International Study of Achievement in Mathematics: A Comparison of Twelve Countries (John Wiley and Sons: New York, NY). John P. Keeves (2011). “IEA: from the Beginning in 1958 to 1990” Chapter 1 in IEA 1958-2008: 50 Years of experiences and memories, edited by C. Papanastasiou, T. Plomp, and E. Papanastasiou (Cultural Center of the Kykkos Monastery: Nocosia, Cyprus).

Vescio, V., Ross, D. and Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning.” *Teaching and Teacher Education, 24,* 80–91.

About College Board

College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900 College Board was created to expand access to higher education. Today, the membership association is made up of over 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success—including the SAT® and the Advanced Placement® Program. The organization also serves the education community through research and advocacy on behalf of students, educators and schools. For further information, visit collegeboard.org.