6 Helping Youths Score Well on AP Examinations in Physics, Chemistry, and Calculus

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Abstract

Special supplementary courses in physics, chemistry, and calculus were developed to prepare mathematically apt high-school students for the AP examinations in those areas. The courses, texts, and instructional approaches are described. Overall, SMPY students who remained in the classes throughout the year scored as high as or higher than the average highly able student taking the examination; most scored well enough to qualify for college credit. The students for whom the AP-level classes proved most beneficial were young, oriented toward careers in science or mathematics, academically motivated, and highly able mathematically. Several specific recommendations for improving future courses of this type are offered.

Many intellectually talented students find that the level and speed of instruction offered in the typical secondary school do not challenge them. Fast-paced instruction is one potential solution (see Fox 1974; George 1976; George & Denham 1976; Stanley 1976; Bartkovich & George 1980; Mezynski & Stanley 1980; Bartkovich & Mezynski 1981), and there are many others (e.g., early graduation from high school, taking college courses part time while still in high school). A particularly feasible option for many is the Advanced Placement Program (AP), which was begun by the College Board in 1955 (Benbow & Stanley 1978; Hanson 1980). Through the AP, high-school students are able to do college-level course-work and receive college credit by examination in a wide range of subjects.

In this chapter we discuss three experimental AP classes that were conducted by the Study of Mathematically Precocious Youth during the 1979–80 academic year. These were physics (Level C, both parts: mechanics, and electricity and magnetism), chemistry, and mathematics Level BC (the more comprehensive of two calculus programs offered by AP).

Earlier AP Classes

The 1979–80 classes were not the first AP courses sponsored by SMPY. Supplementary AP calculus classes were held during the 1974–75 and 1975–76 school years. The details and results of those classes are discussed in Stanley (1976, pp. 146–50) and Mezynski and Stanley (1980). In general, the students became well prepared for the AP examination in Level BC mathematics: the vast majority of them scored well enough to qualify for two semesters of college credit. Students in both classes received higher scores than high-school students who had not received the supplemental instruction.

A third AP calculus class was conducted during the 1978–79 school year. Results from this class have not been formally reported elsewhere and are therefore summarized herein and in table 6.1.

Although the previous two classes had been taught by a college professor, this one was taught by two college undergraduates (both of whom had prior "fast-paced" teaching experience from SMPY-sponsored precalculus classes). The students were all quite young, even by the stan-

TABLE 6.1. 1978–79 AP Calculus Students

Student	Age[a]	Grade in School	Score[b]	May, 1979, AP Calculus BC Grade
1	12, 10	8	129	5
2	13, 7	9	189	5
3	13, 11	10	150	5
4	11, 8	9	124	4
5	13, 5	9	114	4
6	14, 7	9	85	3
7	14, 8	10	100	3
8	15, 11	10	101	3

[a] As of September 1, 1978, in years and nearest month.
[b] Possible score ranges: 5: 127–210; 4: 103–26; and 3: 79–102.

dards of SMPY's first calculus class. In September of 1978 the youngest student (who was also the only female) was 11 years, 8 months old; only one student in the class had reached the age of 15. The participants had received most of their precalculus instruction during SMPY's 1978 summer mathematics institute (see Bartkovich & Mezynski 1981).

All eight students who enrolled in the course took the Level BC mathematics examination in May of 1979. Three students received the highest possible score of 5 (see table 6.1). A 14-year-old boy earned one of the highest point scores in the country (189 points on a 210-point scale, where only 127 points were needed for a 5). No student scored lower than 3 on the 1-to-5 scale, which is high enough to earn credit for two semesters of calculus at most colleges.

RATIONALE FOR THE 1979–80 CLASSES

The results of the three previous AP calculus classes indicated that talented young students could indeed benefit from college-level instruction in mathematics. Not surprisingly, many of the students identified by SMPY as being mathematically able also showed a strong interest in the sciences. It seemed reasonable to offer courses that would give such students a solid foundation in core science subjects (chemistry and physics). AP-level courses in these subjects are less likely to be offered in high schools than are AP calculus or biology. When AP science courses are available, typically the high-school level course is a prerequisite, so a student must spend two school years on that subject. The performance of students in earlier calculus classes indicated that, with appropriately paced instruction, highly able students might successfully consolidate those two years of instruction into one year.

Students were expected at least to be enrolled in their high-school-level course, or, preferably, to have completed it. The students in chemistry and physics had to obtain laboratory experience outside of SMPY's course, since no laboratory work was included. The purpose of all three courses was to provide introductory college honors-level instruction in order to give all students excellent preparation for the AP examination.

Overview of the AP Courses

SMPY's ideal target population was junior- and senior-high-school students who were eager to meet the challenge of college-level course-work and who had shown they were capable of such work. SMPY notified more than 400 high-scoring students from its 1976–77, 1977–78, and 1978–79 talent searches about the AP course offerings. Unfortunately, no talent searches had been conducted by SMPY during the 1974–75 and 1975–76 school years. Those students would have been in the eleventh or twelfth grade and the most likely ones to take advantage of these courses. SMPY found a low response from the younger students (eighth-, ninth-, and tenth-graders). Since so few students enrolled, SMPY extended the opportunity to enroll to older students from Baltimore area high schools. For the high-school students, the following Scholastic Aptitude Test (SAT) scores were suggested as minimal qualifications for enrollment: a mathematics (SAT-M) score of at least 600, and a combined SAT-M and verbal (SAT-V) score of at least 1,000. Consequently, roughly one-half of each class was composed of students of the regular age for the course-work, some of whom were only marginally qualified to participate. The ages and grade levels of the students who enrolled were quite diverse. Ages ranged from a 12-year-old female in physics to an 18-year-old male in calculus. With respect to grade placement, the range was eighth through twelfth.

The tuition charged in all three courses was the same: a total of $100 for the two semesters. In addition, students paid for their own textbooks and were responsible for the AP examination fee ($32). Tuition was low because most of the costs were absorbed by National Science Foundation funding.[1]

The classes were scheduled at nonoverlapping times to allow highly motivated students to enroll in more than one of them. Prior to the first instructional meeting, students in all classes attended a two- to three-hour testing session in which several aptitude and achievement measures were administered.

All three courses were taught by college teachers; the professor who had conducted SMPY's first two calculus classes taught that course again. Having taught the same material in college introductory classes, each instructor had clearly defined criteria by which to monitor students' progress. In many cases the lectures were the same ones the instructors used in their college classes, and the in-class examinations often contained many of the same test items. The instructors covered the topics listed in the AP syllabus and in some cases taught additional topics not listed in the AP syllabus. For example, optics and most of modern physics are not included in AP physics Level C, but the professor believed those topics were essential for a sound first-year college physics course.

Each instructor was assigned a college student as a teaching assistant (t.a.). All three t.a.s were young men attending The Johns Hopkins University, and all had been associated with SMPY for several years. They were all accelerated in their high-school and college work. SMPY selected them as role models for the AP students as well as for their competence in their respective subject areas.

Each class met once each week, for a two-and-a-half to three-hour session. Every session compressed the equivalent of an entire week of high-school or college instruction into that one session. For this reason, regular weekly attendance was essential – skipping one class was like missing one full week of school. In all three courses, weekly homework sets were assigned. The students were expected to spend five to ten hours solving problems and studying the textbooks. The relatively heavy assignments were given to help the students assimilate and supplement the lectures.

The Physics Class

The professor teaching the physics class designed the instruction to be similar to the regular introductory physics course given at Johns Hopkins. The textbook and workbook were by Bueche (1975a,b). During the fall semester the first seventeen chapters of the book were covered, which completed the study of mechanics. The last thirteen chapters, covering electricity and magnetism (E & M), were taught in the spring.

Of the thirteen students initially enrolled, ten persisted through May. The ages, sex, and school grades of the physics students are given in table 6.2. Note that nine of the thirteen students were younger than 16 years when the class started in September. One student was only 12 years and 8 months old. Only four students were high-school seniors.

Since calculus was used in both the textbook and lectures, all students were strongly encouraged to have studied that course previously or to take it concurrently. The two students (numbers 11 and 12 in table 6.2) who dropped out of physics during the fall were the only ones who had no calculus background. Of the three students who were taking calculus during the year, one (number 13) dropped out, in February. The other two (numbers 9 and 10) received the lowest AP scores in the class on the May physics examination.

ASSESSMENT

Before instruction began, students in the physics class were given two preinstructional measures, the College Board's achievement test in physics and the Owens-Bennett Mechanical Comprehension Test, Form CC (Owens & Bennett 1949). The latter, the most difficult of several forms of that test, was designed as a screening measure for college freshman engineering students. The physics achievement test measures physics knowledge at the high-school level. The results of both tests are given in table 6.3. In most cases scores on the achievement test were above the mean of students who had taken one year of physics, which indicated that almost all of the students were familiar with basic physics content; the average score was the 65th percentile of students who take the test after completing at least one year of high-school physics. Two of the lowest scores were earned by the students who dropped out; the third drop-out

TABLE 6.2. AP Physics Class Students

Student[a]	Age[b]	Grade in School	Calculus Background (AP Calculus grade)
1[c]	13, 10	10	AP BC (5)
2	15, 0	11	AP BC (5)
3	15, 9	10	AP BC (5)
4[c, d]	15, 3	12	AP AB (4)
5[c]	15, 10	11	College course
6[c]	16, 7	11	College course
7[d]	12, 8	10	AP BC (4)
8[c]	15, 8	10	AP BC (3)
9[c]	17, 4	12	Concurrent
10[c]	17, 6	12	Concurrent
11[e]	14, 0	10	No calculus
12[e]	14, 9	10	No calculus
13[f]	17, 8	12	Concurrent

[a] Listed in order of grades (highest to lowest) on the May, 1980, AP Level C physics examination, and within AP grade by age (youngest to oldest).
[b] As of September 1, 1979, in years and nearest month.
[c] Enrolled in chemistry and physics.
[d] Female.
[e] Enrolled in chemistry and physics but dropped out of physics.
[f] Dropped out.

received a score that tied for fourth lowest of the group. Only one of the seven persons whose AP physics grade was 3 or more scored lower on the physics achievement test than did the highest scoring of the other six students.

The mechanical reasoning test results bore little relationship to scores on the physics achievement test or the AP examination. In addition, they did not help differentiate the three drop-outs from those who finished the course. (It is suggestive, however, that the lowest score on CC [29] was earned by a top student whose 5 on AP physics mechanics was the lowest of the four, but who did much better on E & M.)

Two in-class tests were given during each semester. These were constructed in large part by the instructor and t.a., but they also included some problems taken from past AP examinations. One month before the AP test students were given a full practice AP test, the 1974 examination (Pfeiffenberger 1976).

In May of 1980 all ten of the students who completed the course took both parts of the AP physics examination, Level C. This three-hour test is divided into four forty-five-minute sections: mechanics multiple-choice items, mechanics free-response questions, electricity and magnetism multiple-choice items, and electricity and magnetism free-response questions. Separate scores are given for mechanics and E & M, using the 1-to-5-point grading scale, where 3, 4, and 5 are considered excellent grades.

Results on the test ranged widely, with three students receiving 5s on both sections, three making 2s on both sections, three earning 4 on one sec-

TABLE 6.3. Preinstructional Physics Testing Results

	CEEB Physics Achievement		Ownes-Bennett Mechanical Comprehension, Form CC		May, 1980, AP Physics C Grade (and Score)	
Student	Score	Percentile[a]	Score	Percentile[b]	Mechanics	E & M
1	680	76	29	5	5 (47)[c]	5 (63)[d]
2	740	90	41	45	5 (59)[c]	5 (73)[d]
3	800	98	31	7	5 (64)[c]	5 (59)[d]
4	570	41	38	30	5 (57)[c]	4
5	690	78	46	70	4	5 (52)[d]
6	680	76	40	40	4	5 (66)[d]
7	730	87	34	13	3	4
8	680	76	33	10	2	2
9	580	45	36	20	2	2
10	620	58	37	25	2	2
11	460	9	25	3		
12	580	45	34	13		
13	550	34	37	25		

[a] Interpolated from 1976–77 norms.
[b] Based on scores of first-term Princeton University engineering students.
[c] Number of points earned out of possible 90, where at least 45 were needed for a grade of 5.
[d] Number of points earned out of possible 90, where at least 52 were needed for a grade of 5.

tion and 5 on the other, and one student getting 3 on one section and 4 on the other (see table 6.3). The average grade on the test was 3.9 on mechanics and 3.7 on E & M. These were well above the nationwide average of 3.4 on both parts.

The Chemistry Class

Like the physics course instructor, the chemistry instructor designed her lectures to be similar to the ones used in the introductory chemistry course at Johns Hopkins. The textbook used was Dickerson, Gray, and Haight (1974). This was supplemented with two workbooks, Hutton (1974) and Butler and Grosser (1974). Throughout the course problems from previous AP examinations were used occasionally for homework or test questions.

All chapters of the textbook were covered with the exception of chapter 12 (Special Role of Carbon), which was an introduction to organic chemistry. Organic chemistry is not covered in the introductory course at Johns Hopkins. Moreover, the instructor felt that time did not permit its treatment in the AP course, despite its limited inclusion in the AP syllabus. Students were encouraged to study chapter 12 on their own.

Twenty-two students (six female and sixteen male) enrolled in the course. Sixteen of them attended class regularly and two attended

TABLE 6.4. AP Chemistry Class Students

Student[a]	Sex	Age[b]	Grade in School
1[c]	F	15, 4	12
2	M	15, 3	10
3	M	15, 5	9
4[c]	M	15, 10	11
5[c]	M	16, 7	11
6	M	13, 0	8
7[c]	M	13, 11	10
8[d]	M	14, 0	10
9[d]	M	14, 9	10
10	F	15, 8	10
11[c]	M	15, 8	10
12	F	16, 5	12
13[c]	M	17, 4	12
14[c]	M	17, 6	12
15	M	14, 7	10
16	M	16, 5	12
17	F	17, 7	12
18	M	17, 7	12
19[e]	F	15, 10	11
20[e]	M	16, 11	12
21[e]	M	16, 11	12
22[f]	F	17, 11	12

[a] Listed in order of grades (highest to lowest) on the May, 1980, AP chemistry examination, and within AP grade by age (youngest to oldest).
[b] As of September 1, 1979, in years and nearest month.
[c] Enrolled in chemistry and physics.
[d] Enrolled in chemistry and physics but dropped out of physics.
[e] Dropped out.
[f] Enrolled in chemistry and calculus but dropped out of both.

sporadically throughout the year. Two students dropped out of the class after the first semester. In January another two dropped out.

The ages, sex, and school grades of the twenty-two chemistry students are given in table 6.4. Note that a five-year age difference existed between the youngest and the oldest student. The four students who dropped out of the course were the older students: three were seniors in high school and one was a junior. The two students who attended sporadically throughout the year were seniors. This higher level of attrition among older students is consistent with the pattern found in the calculus class, and is discussed later in detail.

ASSESSMENT

The preinstructional measures used for the chemistry class were the College Board's chemistry achievement test, the American College Testing Mathematics Usage Test, and the ACT Natural Science Reading Test. The results are given in table 6.5. Scores on the ACT Mathematics Usage Test ranged from a low of 20 out of 40 (sixty-third percentile) to three perfect

TABLE 6.5. Preinstructional Chemistry Testing Results

Student	ACT Mathematics Usage		ACT Natural Science Reading		CEEB Chemistry Achievement		May, 1980, AP Chemistry Grade
	Score	Percentile	Score	Percentile	Score	Percentile[a]	
1	39	99	44	99	630	67	5[b]
2	33	89	34	85	460	14	4
3	23	69	34	85	600	57	4
4	37	96	41	96	670	80	4
5	40	99	42	96	770	97	4
6	29	80	43	98	560	44	3
7	38	98	38	93	660	77	3
8	35	92	42	96	530	34	3
9	36	95	42	96	610	60	3
10	31	84	41	96	410	5	3
11	36	95	38	93	580	50	3
12	40	99	39	93	590	53	3
13	28	76	45	99	570	47	2
14	34	89	46	99	550	41	2
15	40	99	38	93	410	5	
16	39	99	42	96	600	57	
17	34	89	37	89	500	25	
18	28	76	27	65	520	31	
19	20	63	30	72	450	11	
20	36	95	38	93	580	50	
21	26	73	38	93	510	28	
22	34	89	47	99	650	74	

[a] Interpolated from 1976–77 norms.
[b] She earned 121 points out of the possible 160 used for scoring the AP examination, where at least 113 were required for a grade of 5.

scores (ninety-ninth percentile). The average score was 34, roughly at the eighty-eighth percentile of college-bound twelfth-graders. Of the five students whose scores placed them lower than the eightieth percentile, two dropped out of the class, one attended class inconsistently throughout the year and did not take the AP chemistry examination, one performed poorly in class throughout the year as well as on the AP test (earning a 2), and one received tutoring in mathematics and performed well in class and on the AP examination (getting a 4).

The results of the ACT Natural Science Reading Test indicated that most students in the class had a good general science background. Seventeen of the twenty-two students scored higher than the ninetieth percentile. The median score was at the ninety-fifth percentile. Only two students scored lower than the eightieth percentile; those students also scored lower than the eightieth percentile on Mathematics Usage. One of them dropped out of the class and the other did not take the AP test.

The College Board's chemistry achievement test scores ranged considerably, from a low of 410 to a high of 770 (on a scale of 200 to 800). The mean score was 564, which was approximately at the forty-fifth percentile for high-school students who had completed one year of chemistry.

Overall, in the chemistry class the amount of high-school chemistry knowledge was less than the knowledge of high-school physics in the physics class prior to the beginning of instruction (forty-fifth compared to sixty-fifth percentile). Chemistry achievement test scores for the fourteen students who later took the AP test averaged 585, while for the eight who did not the average was 528. This difference, however, was not statistically significant.

Five in-class examinations (each lasting about one hour) and one take-home test were given during the course. In addition, the free-response section of a previous AP examination was administered under timed conditions approximately three weeks before the May AP examination. During the last six weeks of class, free-response sections from past AP tests were also assigned as homework. The emphasis on AP free-response questions during the end of the course was desirable for the following two reasons: the questions provided a review (and overview) of all topics covered during the year, and students became familiar with the types of questions they would encounter on the May AP examination. Unfortunately, the College Board does not make public the objective (multiple choice) questions from previous tests, except when previously administered examinations are published (e.g., Jones, Kenelly, & Kreider 1975; Pfeiffenberger 1976). None had been published for chemistry. Therefore students had little practice with multiple-choice items. In lieu of official AP multiple-choice items, the students were given a timed, in-class test using Part I of Raymond's (1979) multiple-choice examination. This examination was designed as part of an annual competition for high-school seniors who studied Dickerson, Gray, and Haight (1979).

Students in the AP chemistry class were quite heterogeneous in terms of ability, chemistry background, and motivation to do class work. As a group these students were the least able compared with those in physics and with those who completed the calculus course. Not surprisingly, the AP results for this class reflected the differences between the students. Of the eighteen students who completed the course, four failed to take the AP examination (two of them were students whose attendance had been inconsistent throughout the year). Of the fourteen students taking the three-hour AP test (half-objective, half-essay), one scored a 5, four made 4s, seven scored 3s, and two scored 2s. Thus, the average for those in the class who took the AP test was 3.3, while the national average is 3.0.

The Calculus Class

The text used in the AP calculus course was Leithold (1976). Fourteen of the sixteen chapters were covered; excepted were chapter 12 (on hyperbolic functions) and chapter 14 (on conic sections). Differential equations were not included in the textbook, but some aspects of them were covered in class. All topics on the syllabus recommended by the College Board for Level BC mathematics were covered during the year.

Seventeen students enrolled in the course (seven females and ten males). The ages ranged from 13 years, 1 month, to 17 years, 11 months. Ten of the students were older than 16 years. Nine of them were twelfth-graders, and one was already a high-school graduate (see table 6.6).

One student withdrew from the course after four weeks. By early November it was clear from homework and in-class performance that many students were not doing well in the course. A letter was sent to all members of the class reminding them of the importance of regular class attendance and the necessity of spending several hours each week completing assignments. Finally, students were warned that SMPY would ask any person whose work was not satisfactory or showed no improvement to withdraw from the course. At the end of November six students were asked to leave and four others were placed on probation. Of the latter, two dropped out immediately and the other two were asked to withdraw in the latter part of December. Six of the initial seventeen students completed the course. This high rate of attrition is atypical of two of the three previous fast-paced calculus classes conducted by SMPY.

ASSESSMENT

Prior to their instructional meeting, the calculus students were administered the Quantitative Evaluative Device (QED; see Stake 1962) and the College Board's achievement test, Mathematics Level II. The scores are presented in table 6.7. The average score on the QED was 35 out of 60 possible points. The six students who finished the course averaged 38 on QED, while the eleven who did not finish averaged 34. This difference is not statistically significant.

The College Board's Mathematics Level II achievement test clearly differentiated between those who completed the class and those who did not. For the whole group the average was 675 (out of 800). The six students who finished averaged 773 (three of these were 800s). The eleven who did not finish averaged 622. This is a 151-point difference. It was especially interesting that on this test score distributions between the two groups did not overlap. Every student finishing the course scored higher than any student not finishing the course.

By the end of the course, six teacher-designed in-class tests had been given, each taking half of a class period (roughly eighty minutes). In March an eighty-minute standardized calculus test, Cooperative Mathematics Tests series, Calculus, Form B, was given. This test was administered to see how the class's performance compared with performance on the national level. One student scored at the ninety-fourth percentile, and the other five scored at or above the ninety-ninth percentile based on

TABLE 6.6. AP Calculus Class Students

Student	Sex	Age[a]	Grade in School
Completed course			
1	M	13, 1	9
2	F	14, 8	11
3	M	14, 11	10
4	M	16, 9	12
5	F	17, 5	12
6	M	17, 10	High-school graduate
Did not complete course			
7	M	14, 6	10
8	M	14, 7	9
9	M	14, 10	10
10	M	15, 2	10
11	F	16, 8	12
12	M	16, 9	12
13	M	16, 10	12
14	F	17, 5	12
15	F	17, 5	12
16	F	17, 5	12
17[b]	F	17, 11	12

[a] As of September 1, 1979, in years and nearest month.
[b] Enrolled in chemistry and calculus, but dropped out of both.

national high-school norms. Scores ranged from 49 to 58 points out of a possible 60. In April, several weeks prior to the May AP calculus test, students were given a full practice AP test under standard three-hour testing conditions. The May 1973 test was used (Jones, Kenelly, & Kreider 1975).

The grades of the class on the official May, 1980, AP examination were exceptional: all six students made the highest possible, 5. The national mean grade on that test was 3.2. Even more strikingly, on the 210-point scoring scale, where at least 144 points were needed for a grade of 5, the lowest scoring of the six exceeded that minimum by 13 points; the other five students were at least 33 points above it, and one – with 190 points – was 46 points ahead (table 6.7, last column). The grade of 5 is equivalent to *A*+ in two semesters of calculus at a college or university such as Johns Hopkins.

Discussion of AP Results

There are many potential reasons for the differentiation in preparation for the AP between the physics, chemistry, and calculus classes. Clearly, high ability and a great deal of intrinsic motivation are required of the students. It also seems that a teacher's firm, steady insistence on maintain-

TABLE 6.7. Preinstructional Calculus Testing Results

Student	QED[a]		CEEB Mathematics Achievement, Level II		May, 1980, AP Calculus BC
	Score	Percentile[b]	Score	Percentile[c]	Grade (and Score)[d]
1	34	89	800	91	5 (181)
2	49	99.5	800	91	5 (178)
3	38	96	740	74	5 (177)
4	35	91	730	71	5 (190)
5	29	74	770	83	5 (157)
6	44	99.5	800	91	5 (187)
7	38	96	670	46	
8	35	91	580	17	
9	33	87	620	27	
10	36	93	640	34	
11	40	98	720	65	
12	31	82	580	17	
13	32	85	610	24	
14	25	58	600	21	
15	32	85	570	15	
16	34	89	620	27	
17	33	87	630	31	

[a] Quantitative Evaluative Device (R. E. Stake, "A Non-Mathematical Quantitative Aptitude Test for the Graduate Level: The QED," *Journal of Experimental Education* 31 [1, Sept., 1962]: 81–83).
[b] Based on 925 postbaccalaureate persons desiring to qualify as graduate students in education at the University of Nebraska.
[c] Interpolated from 1976–77 norms.
[d] Of the possible 210 points, 144 or more were required for a grade of 5.

ing high standards for student performance is an important factor for successful AP preparation.

In comparison with that in the courses in calculus and physics, less emphasis was placed in the chemistry class on diligent completion of homework assignments or on regular class attendance. Early in the school year a fundamental philosophical difference was apparent between the instructors in calculus and physics versus the chemistry instructor. The chemistry instructor's philosophy was that the AP course was an enriching experience for the students. In addition, she believed that even if the students did not get college credit for their efforts, they would receive a good background to build on later. The emphasis was on gaining exposure to concepts. The students could do as much or as little work as they wished.

In sharp contrast, the calculus and physics instructors insisted on regular class attendance and thorough completion of weekly assignments. Students in both of these classes were aware that failure to make consistent efforts would result in their dismissal from the course. In fact, a large number of students in calculus (eleven out of seventeen) either dropped out on their own or were asked to leave. The calculus and physics instructors were strongly oriented toward teaching a year of college-level course-work, with the expectation that their students would subsequently be well prepared for more advanced study in their respective subjects. Explicit attrition from the chemistry class (eighteen percent) was lower than that in either of the other two classes (65 percent for calculus and 23 percent for physics), perhaps because less effort was required from the students in terms of homework and attendance. In supplementary courses such as these, attrition is likely to occur among the less motivated or less able students. This is especially true if the course requires considerable effort. The greater the attrition, the more select the final group becomes. Thus one would expect the test scores for these remaining students to be excellent.

In the calculus class, all students scored a 5 on the AP exam. Only six of the original seventeen completed the course, however. Physics students averaged 3.8 on the AP test, with all ten of the students who remained (of the thirteen who began the class) taking the test. Four students dropped out of chemistry. Of the eighteen who completed chemistry, four did not take the test. The scores of the fourteen who did averaged 3.3.

Attrition

It was suggested earlier that attrition from the AP classes was at least partially a function of the degree of effort required of the students by the instructor. If this was true, what types of students were most likely to persist? Several comparisons were made between students who completed a class and those who dropped out.

An analysis was made of attrition from the three calculus classes (1974–75, 1975–76, and 1979–80), which were all taught by the same instructor. In the 1974–75 class fifteen students enrolled and thirteen completed the class. The majority of students in this first class were young (tenth grade) and had learned much of their precalculus mathematics in SMPY-sponsored fast-paced courses. The 1975–76 calculus class initially enrolled twenty-three students, most of whom were juniors and seniors in high school. Eleven students dropped out. In the 1979–80 class only six of the original seventeen students completed the course. Thus of a total of fifty-five students enrolled in these three classes, thirty-one finished the course and twenty-four did not. The average SAT-M and SAT-V scores of the students who finished as well as those who dropped out can be seen in table 6.8. The average SAT-M score for those finishing was 689; for those who dropped out it was 647. A *t*-test of the difference was significant past the .05 level. The average SAT-V score for those dropping out (536), however, was higher than that for those who finished (516). Although this 20-point difference was not statistically significant, fifteen of the thirty-

TABLE 6.8. SAT Scores for Three AP Calculus Classes

	Students	
	Completed Course (N = 31)	Dropped Out (N = 24)
Average SAT-M	689	647
Average SAT-V	516	536
Average SAT-M plus SAT-V	1,205	1,183
Average difference: SAT-M minus SAT-V	172	111

TABLE 6.9. SAT-M Scores for Three AP Calculus Courses (by Age)

	Students			
	Younger than 16 Years Old		16 Years Old or Older	
	Completed Course (N = 16)	Dropped Out (N = 7)	Completed Course (N = 15)	Dropped Out (N = 17)
Average SAT-M	653	624	727	656

one students who completed the course had SAT-M scores *at least* 200 points higher than their SAT-V scores, while only three of the twenty-four students who dropped out had scores that differed so greatly. These comparisons suggest that students whose aptitude for mathematics far exceeds their verbal aptitudes have more interest and motivation to be successful in a fast-paced mathematics class. In contrast, when verbal scores are quite high compared with mathematics scores, the students may tend to have stronger interests in subjects other than mathematics.

The relationship of age, SAT scores, and attrition was also examined for the three calculus classes. The results can be seen in table 6.9. Students were divided into two categories: those who, when the course began, were younger than 16 years (N = 23) and those who were 16 years or older (N = 32). Only 30 percent of the younger students dropped the course (seven of twenty-three), while 53 percent of the older students dropped out (seventeen of thirty-two).

The SAT scores given in table 6.9 cannot be compared directly across age groups. Undoubtedly, the SAT-M scores of the younger students would increase with age. It seems, however, that SAT-M is a better predictor of attrition for older students than for younger ones. A within-age-group comparison showed that there was only a twenty-nine-point difference in SAT-M scores between the drop-outs and non-drop-outs in the young group. The difference of seventy-one points found for the older group was significant at the .01 level. These findings are consistent with a general hypothesis that (possibly because of previous exposure) the younger students were better prepared for a fast-paced class than the older ones were. The older students coming from regular-paced instructional backgrounds were less likely to remain in the class unless they had high mathematical reasoning ability.

In addition to examining attrition from the calculus classes, a comparison was made among students in the three 1979–80 courses. A comparison of twelfth-graders with students in all lower grades combined indicated that a twelfth-grade student was more likely to drop out than a non-twelfth-grader was. This information is presented in table 6.10. Fifty-two students were enrolled in calculus, chemistry, and physics (any student enrolled in two of the classes was counted twice). Thirty-four students finished the course in which they were enrolled; eighteen did not. Forty-four percent of the twelfth-graders dropped out, while only 25 percent of students in lower grades did. The higher percentage of twelfth-grade students dropping out might be explained by less motivation to succeed. The class was not as "accelerative" for the twelfth-graders as it was for the younger students. It is also possible that the older students had acquired poor study habits in slower-moving high-school classes. Older students were also more likely to have other commitments, such as a part-time job. Finally, many of the younger students had had previous exposure to fast-paced instruction, while few of the twelfth-graders had. Experience with the demands of fast-paced course-work may provide important preparation for classes such as these and serve as an excellent screening method.

Homework and Tests as Predictors of AP Performance

Based on experience with previous fast-paced courses, it was expected that diligent completion of homework assignments would relate positively to in-class test scores and subsequent AP examination performance. These relationships were examined separately for calculus, chemistry, and physics.

TABLE 6.10. Attrition in 1979–80 AP Classes (by School Grade)

	Students: All Three Courses					
	Before Twelfth Grade		Twelfth Grade		Total	
	Number	Percentage	Number	Percentage	Number	Percentage
Completed course	21	72	13	56.5	34	65
Dropped out	8	28	10	43.5	18	35
Total	29		23		52	

Differences in homework and in-class performance between the calculus students who completed that course versus those who did not were large. Perhaps some of the students who performed poorly were in fact working hard but were not ready for the high level of course content. Others clearly were making little effort. The six students who finished the calculus course probably had the strongest mathematics backgrounds of all seventeen students. In addition, they were willing to spend time completing the assignments. Although there was a fairly consistent rank-ordering of the students on homework and test scores, even the weakest student in this group scored extremely well (thirteen points above the minimum score for a 5) on the AP examination.

In both the chemistry and the physics classes, performance on the AP test was heterogeneous enough to warrant investigation of the relationship between homework and in-class test scores and AP test results. In each class some support was found for the conclusion that good in-class performance was required for success on the AP examination. Table 6.11 gives for the chemistry students the intercorrelations of homework, in-class tests, the practice AP test (essay section only), and the May AP examination. Although all the correlation coefficients were positive and moderately large, because of the small number few were statistically significant. In-class tests correlated .70 with the practice AP test scores and .60 with the May AP test results. It is unfortunate that only the essay section of the chemistry AP test was available for practice. Had the class been able to take a full practice test the correlation between it and in-class tests, as well as the May AP test, probably would have been increased. (The essay section contains far fewer items than the objective section and is scored somewhat subjectively. Hence, scores on it tend to be considerably less reliable than for the full AP test, which includes multiple-choice items.) The correlation of homework scores with AP test scores was a surprisingly low .39.

A similarly low correlation was found for the physics students between their homework scores and May AP test scores. These and other correlation coefficients are given in table 6.12. Mechanics and E & M data are

TABLE 6.11. Intercorrelation of Chemistry Student Performances in Four Areas ($N = 14$)

	Homework	In-Class Tests	Practice AP Chemistry Test
Homework			
In-class tests	.53*		
Practice AP chemistry test	.42	.70**	
May, 1980, AP chemistry test	.39	.60*	.50

*$p < .05$.
**$p < .01$.

TABLE 6.12. Intercorrelation of Physics Student Performances in Four Areas ($N = 10$)

		Homework		In-Class Tests		Practice AP Physics Test	
		M	E & M	M	E & M	M	E & M
Homework	M						
	E & M	.59					
In-class tests	M	.68*					
	E & M		.71*				
Practice AP	M	.42		.88***			
physics test	E & M		.52		.82**		
May, 1980, AP	M	.36		.85**		.84**	
physics test	E & M		.36		.68**		.59

*$p < .05$.
**$p < .01$.
***$p < .001$.

treated separately. Many of the *r*s fail to reach the .05 level of significance, again because of the small sample size. Homework performance correlated best with in-class test scores, which were highly related to May AP test scores. In general, in-class and practice AP test scores predicted May AP scores better for mechanics than for E & M.

Despite the relatively weak *direct* relationship between homework and May AP test scores, homework performance showed a clear relationship with in-class test scores. This indicates that over shorter periods of time the effect of homework is quite strong.

Evaluation of the 1979–80 AP Classes

In evaluating the success of the AP classes, two criteria were considered. First, how many students scored well enough to receive college credit? Second, how did SMPY's students score in comparison with the national results and with a representative public school district?

Many colleges and universities grant full course credit for a grade of 3 or higher on the AP examination. Based on this, 100 percent of the six calculus students qualified for two semesters of college credit.

In the physics course, 70 percent of the students who completed the course scored well enough to receive two semesters of college credit. The other 30 percent, with only 2s, would probably receive not even one semester of physics credit.

In chemistry, fourteen of the eighteen students finishing the course took the AP examination. Eleven of them scored 3 or higher, representing 61 percent of those who finished the course.

In summary, most of the students who remained in the classes throughout the year did score well enough to qualify for college credit at institutions accepting 3s for this purpose.

TABLE 6.13. Performance of SMPY's Students, a Public School System's Students, and Students Nationwide

	Score	SMPY's May, 1980, Results (%)	Public School Results (%)[a]	May, 1980, National Results (%)
Physics C, mechanics	5	50.0	12.7	24.5
	4	20.0	13.8	26.8
	3	0	21.8	19.4
	2	30.0	32.2	19.2
	1	0	19.6	10.1
Average		3.90	2.68	3.36
N		10	87	2,121
Physics C, E & M	5	40.0	5.7	26.0
	4	20.0	15.5	26.0
	3	10.0	31.0	19.4
	2	30.0	22.6	15.8
	1	10.0	25.3	12.8
Average		3.70	2.54	3.37
N		10	71	1,690
Chemistry	5	7.1	11.3	12.9
	4	28.6	22.0	19.5
	3	50.0	43.5	36.3
	2	14.3	16.6	19.9
	1	0	6.4	11.4
Average		3.29	3.15	3.03
N		14	282	8,209
Calculus BC	5	100	12.2	21.8
	4	0	18.7	20.7
	3	0	29.9	26.5
	2	0	20.6	16.3
	1	0	18.0	14.7
Average		5	2.87	3.19
N		6	1,599	7,783

[a] Results obtained from reports from the Fairfax County Public Schools of Northern Virginia, 1974–80.

The scores of students in all three courses were equal to or higher than nationwide AP examination performance levels. Table 6.13 is a presentation of the results for the May, 1980, AP examinations for SMPY's students, students in a public school system, and students nationwide in physics, chemistry, and calculus.

The physics students in SMPY's course exceeded the national averages on both the mechanics and the E & M sections. This was due to a relatively high proportion of 5s on each section. The average mechanics grade for SMPY's class was 3.90, with 70 percent earning 3 or higher. The national average, based on 2,121 students, was 3.36, with 71 percent earning 3 or more. On E & M, the average for SMPY's class was 3.70, with 70 percent earning at least a 3. Nationally, the 1,690 students taking E & M averaged 3.37, and 71 percent received grades of 3 or higher.

The grades earned by SMPY's chemistry students were slightly higher than those earned at the national level. A total of 8,209 students took the

AP chemistry examination; their grades averaged 3.03. SMPY's students averaged 3.29; of the fourteen students taking the test, 86 percent earned grades of 3 or higher. Nationally, 69 percent of the students obtained at least a 3.

In calculus, 22 percent of the 7,783 students taking the Level BC examination earned a 5; the average was 3.19. In comparison, 100 percent of SMPY's calculus students received a grade of 5.

For all three courses, then, SMPY's students performed as well as or better than students nationwide.

Information about student AP achievement was obtained from the Fairfax County Public Schools of Northern Virginia for a comparison with SMPY's students' scores.[2] The data from seven years (1974–80) were combined and averaged (see table 6.13). Scores were available only for twelfth-grade students. Over seven years, a total of 1,599 students in Fairfax County took the Level BC mathematics examination (about 228 students per year). Their average grade was 2.87, with 61 percent receiving 3 or higher. In chemistry, 282 students (40 per year, on the average) took the AP test. Their mean grade was 3.15, with 78 percent earning 3 or higher. Not many county students took the physics Level C examinations in mechanics or E & M. The totals for seven years were 87 (12 per year) and 71 students (10 per year), respectively. The average mechanics grade was 2.68; about 48 percent earned at least a 3. On E & M, the average was 2.54; 52 percent received a 3 or higher.

In summary, the performance of SMPY's AP students was equivalent to the levels shown by the Fairfax County school system for chemistry, but exceeded the performance of that county's students on mathematics and physics. This was the case despite the fact that SMPY's students were younger on the average and that each year only a select few of the approximately 10,000 seniors in Fairfax County's twenty-three senior high schools took the examinations.

STUDENTS' EVALUATIONS

In addition to the quantitative comparisons of course success, a valuable source of evaluative information was the students' opinions of the courses. During the summer following receipt of the official AP score, a questionnaire was mailed to all students who had enrolled in the 1979–80 courses. The questionnaire was designed to assess the students' opinions toward the classes, especially regarding AP test preparation. The response rate was 100 percent for all three courses. Tabulations by class of responses to some questionnaire items are given in table 6.14. Note that the percentages given in table 6.14 were calculated based on all students who enrolled, including those who dropped out and/or did not take the AP examination.

TABLE 6.14. Students' Evaluation of 1979-80 AP Courses (in Percentage)

		Calculus (N = 17)	Chemistry (N = 22)	Physics (N = 13)
1. Did you think SMPY's course as a whole prepared you well for the AP exam?	Yes	35	50	54
	No	0	23	23
	Didn't take exam	65	27	23
2. Even if you do not get any college credit for the course, do you think it was a worthwhile experience?	Yes	35	73	77
	Somewhat	8	9	15
	Not sure	18	5	8
	No	18	9	0
	No response	12	5	0
3. Would you recommend this course to a qualified friend?	Yes	65	73	92
	Not sure	18	18	8
	No	18	9	0
4. How have your feelings toward the subject changed as a result of your experience with SMPY's course this year?	Like more	12	64	77
	No change	77	23	23
	Like less	12	14	0
	No response	0	0	0
5. Has this course influenced your decision to study the subject further in the future?	Yes	18	41	69
	No	71	41	31
	No response	12	18	0

Responses to the first question (Was SMPY's course good preparation for the AP test?) generally were favorable from students who took the test. All six students who took the calculus test thought SMPY's course provided good preparation. In chemistry, ten (71 percent) of the fourteen students who took the AP exam thought the course was good preparation, as did 80 percent of the ten students who took the physics AP test.

Answers to the second question indicated that all six students who took the AP mathematics test thought the calculus course was a worthwhile experience. Students who had not completed that course showed ambivalent or negative reactions. A more uniformly positive response was found in the chemistry and physics classes. In chemistry, 82 percent felt that the course was at least somewhat worthwhile, as did 92 percent of the physics students.

Another indication of students' opinions about the courses was their willingness to recommend them to a friend. Of the calculus students, 65 percent said they would recommend it, while 73 percent and 92 percent of the chemistry and physics students, respectively, said they would. Therefore, even though some of the students had doubts about how useful the course had been for them, most felt it would benefit other qualified individuals.

Regarding attitude changes as a result of the courses (questions 4 and 5 in table 6.14), a discrepancy was observed between the calculus and science students' responses. Most of the calculus students (77 percent) reported that their liking for mathematics had not changed, while 64 percent of the chemistry students and 77 percent of the physics students said their liking for the subject had increased. A similar pattern of responses was observed regarding whether students would be likely to study the subject again in the future. Possibly this discrepancy reflects the different amounts of prior exposure to the subject students were likely to have had. Chemistry and physics were probably more unfamiliar to the students before they took the courses; they could not know a priori if they would like these subjects. In contrast, students who enrolled in calculus had had considerable prior experiences with mathematics and presumably already had favorable attitudes toward it.

When considering the questionnaire responses as a whole, it was found that reactions were generally less favorable from the students who dropped out. Those who completed the courses and took the AP examination were almost without exception uniformly positive in their reactions to the class.

Conclusions and Recommendations

One of the most salient findings of the 1979–80 AP courses was that the greatest success was obtained with the younger students. For a combination of reasons, the participants who had not yet reached the twelfth grade (or twelfth-graders who were young in grade) were more likely to persist and do well in the courses. Alternately, they may have been abler than their regular-aged twelfth-grade counterparts. These conclusions had been drawn previously from the three AP-level SMPY calculus courses (1974–75, 1975–76, and 1978–79). (See Mezynski & Stanley 1980.) The 1979–80 chemistry and physics courses demonstrated that the younger students do better in the sciences, also.

The courses did help to prepare students for the AP examinations. One criterion was the number of participants who scored high enough to qualify for college credit. All of the calculus students finishing the course did so, as did 61 percent of the chemistry students and 70 percent of the physics students. Relative to national levels, SMPY's calculus and physics students exceeded the average of highly able students taking the examinations. The chemistry class average was about equivalent to the national norms, but a greater percentage of SMPY's students scored 3 or higher. SMPY's students in calculus and physics surpassed the achievement levels of high-school seniors from an excellent county public school system near Washington, D.C., while the chemistry class's performance was about the same as the public school seniors'. Since virtually none of the students in SMPY's courses was receiving AP-level instruction in their high schools, we can conclude that the weekly sessions were largely responsible for the AP results. Thus with about one-half the amount of formal instruction (and, in chemistry and physics, no laboratory experience), SMPY's students performed as well as or better than the highly selected students who study AP courses in their high schools and then take the AP examinations.

Other conclusions drawn from SMPY's courses concern the type of background needed for successful performance in AP-level mathematics, chemistry, and physics. All four calculus courses offered by SMPY indicated that students with previous experience in fast-paced mathematics classes do better than students who have had regular mathematics backgrounds. Successful experience in fast-paced classes is indicative of three prerequisites for success in AP calculus: mathematical reasoning ability, a good foundation in precalculus mathematics, and a high level of motivation. Hence the fast-paced classroom experience itself is not essential if students can be screened well for aptitude and knowledge. The College Board's mathematics achievement test, Level II, is a particularly useful screening device for the latter.

In chemistry and physics there seemed to be no difference between students who had already completed the high-school-level course and those who were taking it concurrently with SMPY's AP-level course. The most important implication of this is that highly able, well-motivated students need not spend two school years studying a course through the AP level (when the high-school course typically is a prerequisite). Consequently, they could take several AP-level science courses during their high-school years. In fact, several students in SMPY's courses completed *both* chemistry and physics at a high level, indicating that well-motivated, exceptionally able students can learn two different AP-level science courses in only one year. In physics, however, it was shown that calculus was a needed prerequisite.

In summary, the population of students for whom SMPY's AP-level courses were most beneficial was young (median school grade, ten), science- or mathematics-career oriented, motivated to move ahead academically, and highly able mathematically. Given a group of students which met those criteria, the courses would probably be satisfactory without major improvements in format or technique. Consequently, the chief recommendation for improving future courses of this type is to improve methods of screening applicants. Several other recommendations can be made on the basis of student questionnaires and informal discussions with the instructors:

1. A laboratory facility for the chemistry and physics courses, while not essential, would provide valuable "hands-on" experience.
2. Lectures should incorporate more problem solving and applications of the topics.
3. The teaching assistant should be accessible before and after class to work with students who need extra help.

4. Short quizzes should be given weekly; longer tests should continue to be administered on a four-to-six-week basis.

5. Individuals who consistently perform below the instructor's standards should be warned, then placed on probation, and, if necessary, dismissed from the class.

AP-level courses of the type conducted by SMPY have shown themselves to be very beneficial to highly motivated, extremely able students. These courses are particularly useful to students who have no access to AP-level instruction in high school, who are ready for it before the twelfth grade, and/or who do not wish to spend two full school years on one subject. The chief difficulty in conducting such courses is attracting a sufficiently large number of qualified individuals to make the program feasible.

RESIDENTIAL SUMMER HIGH-SCHOOL-LEVEL SCIENCE COURSES

The key problems with such recruitment seem to be distance and time. All six of the supplemental AP courses described herein were nonresidential; students had to commute from their homes to the Johns Hopkins campus and back approximately thirty Saturdays or Sundays during the school year. Some came long distances. Others lived too far away to make taking the course feasible. Many potential members of these classes had other activities on weekends that interfered.

In collaboration with SMPY, the Center for the Advancement of Academically Talented Youth at Johns Hopkins has conducted three-week, intensive residential courses for four summers (1980, 1981, 1982, and 1983) in order to permit intellectually talented students from all over the Middle Atlantic Region and, indeed, the entire country to accelerate and enrich their knowledge of several subjects. In 1982, for the first time, the equivalent of one school year of high-school biology was offered in three concentrated weeks to certain highly selected 12- to 15-year-old students. This course, conducted at Franklin and Marshall College in Pennsylvania, included some experience in a college biology laboratory.

During the subsequent three weeks, chemistry was offered in the same way. Thus students could elect to study biology in the first session and chemistry in the second. High-school physics was offered for the first time during the summer of 1983. Biology and chemistry were also available then, both each session, so the ablest students had their choice of any two of the three. They were expected to have completed most of precalculus already (and, for physics, one year of calculus). Precalculus is available at each of the two three-week sessions each year.

It may seem strange for us to recommend high-school-level courses after extolling the virtues of AP-level ones. The main purpose is to save the brilliant student from being incarcerated for 180 to 190 periods in a routine biology, chemistry, and/or physics course when he or she could learn the basic material well among intellectual peers in five or six hours per day for three weeks. In the subsequent school year the student should be able to work on the AP level of the course in whatever fruitful ways can be devised in the local school context. If an excellent AP course is available in the high school, the student will be ready for it. If supplemental AP courses such as those described earlier in this report are available, his or her progress in them is likely to be excellent. The best solution under some circumstances will be to take a college course for credit at as excellent a tertiary institution as the student can reach regularly, and then take the AP exam.

Another sequel to the summer courses that SMPY is exploring for a special subgroup, its extremely special youths who before age 13 have scored at least 700 on the mathematical part of the College Board's Scholastic Aptitude Test, is providing skilled "mentors-by-mail" to help students learn AP-level calculus, biology, chemistry, and/or physics. Initial results with calculus, biology, and chemistry are encouraging, but obviously this method demands great academic maturity from the "mentees," their parents, and their teachers. Other follow-up procedures, where available, will usually be preferable for most students.

Entering college two years early with full sophomore-year standing in calculus, physics, chemistry, biology, and several other subjects is an attainable goal for several hundred youths across the country each year. Most of them will be able to obtain an excellent college education in three, two and one-half, or even two years. Savings of money and time and prevention of boredom will be among the rewards. For other intellectually talented youths who are less accelerable than these several hundred out of more than three million students their age, the pace will be slower. By age 16, however, at least fifty thousand of the age group could benefit greatly from one or more AP-oriented mathematics and science courses. We urge communities, colleges, and universities to help make this possible.

Notes

1. This study was prepared with the support of National Science Foundation Grant SPI 78-27896 for calculus and Grant SED 79-20868 for chemistry and physics. Any opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the National Science Foundation.

2. We are indebted to Joseph Montecalvo for providing us this valuable information.

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