

Learning and Understanding: Improving Advanced Study of Mathematics and Science in US Schools by the Committee on Programs for Advanced Study of Mathematics and Science in American High Schools.

1. Introduction

a. Background

- i. Many American students are shown to be not taking bona fide advanced classes.
- ii. AP and IB enrollment continues to grow (more than 200% increase from 1990 to 2000),
- iii. The quality of these programs is cause for concern.
- iv. Racial and economic gaps exist.

b. Brief overview

- i. AP launched in 1955 to provide introductory college level classes to high school students.
- ii. Now used as a basis for granting credit or advanced placement for college freshmen.
- iii. IB developed to provide international standard for children who travel frequently (say, children of diplomats).
- iv. Classes are interrelated – schools cannot offer only a subset of IB classes.
- v. Growing belief that all students should have equal access to quality education programs.
- vi. Concern over integrity and quality even as programs expand.

c. What is advanced study?

- i. Ill-defined – emphasis on concepts rather than facts.
- ii. Sometimes equated with accelerated or college level.
 1. Too much content can take away from understanding.
 2. College classes not necessarily a good model to follow.
- iii. Deep conceptual understanding should be primary goal.

d. Student clientele

- i. Focus on highly motivated and well-prepared students.
- ii. Try to reach as many of them as possible.
- iii. Prerequisite classes are important, no matter how early.

e. Study charge and approach

- i. To consider the effectiveness of and potential improvements to high school advanced study programs
- ii. Lack of systematic data
- iii. Met with representatives of programs, experts, university faculty, etc.

2. Context of Advanced Study

a. Policy context

- i. US high schools consistently criticized for graduating students ill-equipped for college or workplace.
- ii. 1999: Richard Riley, then Secretary of Education, declared it was time to change high schools to align better with modern times.

- iii. Many policymakers and educators turned to AP and IB to improve their academic programs.
- iv. Role and influence of standards and accountability
 - 1. Does setting standards and holding schools accountable actually make education more rigorous?
 - 2. Curriculum is being narrowed, high-quality instruction discouraged
 - 3. Should focus more on funding, teacher quality, and professional development rather than testing.
- v. Financing advanced study programs
 - 1. Substantial variation in distribution of resources.
 - 2. Some schools with high student poverty get less money than more affluent schools in the same district.
 - 3. Funding necessary for teacher professional development, instructional resources, etc.
- vi. Teacher qualifications, certification and challenges
 - 1. Established link between teacher's academic skills and student performance
 - 2. High-poverty schools and schools with concentrations of minority tend to get least experienced teachers.
 - 3. High turnover rates in such schools
 - 4. Teacher certification
 - a. All states have well-defined certification program.
 - b. Alternative licensure originally in place to ease teacher shortage.
 - c. No states require licensure for advanced study.
 - d. No colleges or universities offer teacher preparation programs for teaching advanced study.
 - 5. Teacher shortages
 - a. Problem seems to be distribution rather than shortage.
 - b. Attracting new teachers is a major challenge.
 - c. Salary considerably less than other white-collar jobs.
- b. Educational context
 - i. Preparing for advanced study in middle schools
 - 1. Middle school mathematics and science
 - a. Increasingly many middle schools offering integrated or coordinated science and math.
 - b. Finding qualified instructors for these courses is difficult.
 - c. Curricula tend to lack focus, be repetitive, and implemented inconsistently.
 - d. High school teachers rarely interact with middle school teachers regarding curriculum design.
 - 2. Challenges of middle school teaching
 - a. Teachers in middle school tend to be certified in a different subject area

- b. They do not know their content as well, and are less able to communicate what they know
 - 3. Ability grouping in mathematics
 - a. Some of the ability-based “pipelines” lead away from rigorous courses.
 - b. Students in a lower sequence find it difficult to move up into a more advanced sequenced due to the cumulative nature of mathematics.
 - c. Schools more willing to accommodate requests of middle-class parents than low-income parents.
- ii. Preparing for advanced study in high school
1. Curriculum
 - a. “Differentiated”: Allows students to choose freely.
 - i. Some students choose poorly, and leave school unprepared for college or work.
 - b. “Constrained”: Core curriculum with few choices
 - i. Differentiation happens at the pace of student progressing through the curriculum
 2. High school mathematics and science
 - a. Amount of time spent on instruction and level of courses are strongly related to achievement
 - b. Standards are set at the state or even more local level.
 - c. Most students take science classes in the order of biology, chemistry, physics, and since most states require 2 years of science, most students do not take physics.
 - d. Recently there has been an effort to change the order and put physics first, so that might change.
 3. Challenges of high school teaching
 - a. Teaching responsibilities can be as high as 5 periods a day.
 - b. Usually more than 100 students. Can be as high as 175.
 - c. Difficult to know students well
 - d. No time to meet with colleagues for curricular or instructional planning
 - e. Lack of time
 - i. Some teachers finish what they can and leave the rest uncompleted.
 - ii. Some stay after hours – difficult in some urban schools because of security concerns
 - f. Teachers feel isolated and unsupported.
 - g. Often, only one teacher per department teaching advanced study, feels extreme isolation.
 4. Students
 - a. According to survey, seeing friends in the primary reason for going to school

- b. College-bound students work as many as 15-20 hours per week
 - c. In comparison with other countries, US high school students spend large amounts of free time in nonacademic or even anti-academic activities such as socializing, extracurricular activities, and watching TV.
 - d. Those in advanced study have more frequent demands on their time, such as field trips, competitions, and so on. They often participate heavily in extracurriculars and hold leadership positions.
 - e. Advanced study classes are a haven from distracting disciplinary-problem classes
- c. Disparities in opportunities
 - i. Disparities in participation
 - 1. Correspondence between availability and breadth of AP offerings and racial composition
 - 2. Possible attributions to parental involvement, cultural differences in educational values.
 - ii. Disparities in outcomes
 - 1. Minorities in AP classes still do significantly worse
 - 2. Unclear whether assessment is biased or other factors are overwhelming
 - 3. Improving student success in advanced study includes
 - a. Reducing class size
 - b. Removing low-level classes
 - c. Enhancing professional development
 - d. Hiring and retaining qualified teachers
 - e. Providing information to parents about long-term benefits of advanced study
 - f. Implementing and supporting supplementary educational opportunities
 - g. Increasing student access to counselors and mentors
- d. Connections between advanced study and higher education
 - i. High school-college interface coordination and articulation
 - 1. High school diploma does not guarantee success in college or work, due to disconnecting and decentralized system and lack of standardization.
 - 2. Differing college requirements leave high schools uncertain about what it means for students to be adequately prepared.
 - 3. Belief that AP or IB offers advantage, leading to increasing numbers of students enrolling in these programs
 - ii. Advanced study as a link between high school and college
 - 1. Students and parents look to advanced study programs to facilitate admission to college, to help them succeed in college-level work and gain credit.

2. Teachers expect the courses to equip them with the content knowledge and habits of mind.
 3. Colleges want highly prepared and well educated students
 4. So advanced study classes provide a foundation on which to build higher education
 5. If they are not well constructed, subsequent learning will be affected due to the cumulative nature of science.
 6. Role of advanced study in admissions decisions
 - a. How decisions are made: AP and IB are well-established standards, allowing them to be efficiently selected when admissions decisions are made. Colleges also look at availability of advanced study courses.
 - b. Role of AP and IB in the process: Most important priority for admissions officers is to admit students who can take advantage of the academic strength of the college and contribute to the education of their peers. AP or IB courses indicate willingness to face academic challenges. Two types of schools do not offer AP or IB
 - i. Schools with their own programs
 - ii. Schools with insufficient resources
 - c. In general, selective colleges pick students who took the most challenging program that was available.
 - iii. AP and IB grades and admissions process: Some students take AP classes but not exams.
 1. Reasons could be financial
 2. As scores are not released till after the admissions decision is made, it does not affect it.
 3. As more sophomores and juniors are taking AP classes, this might change in the future.
 - iv. College credit and placement: Students place out of introductory classes, and reduce the time to the degree and hence save on tuition costs. However, some students spend the same amount of time taking a lighter course load, or taking more advanced classes in areas of interest. This is usually a greater motivator than early graduation. Furthermore, some may try to get out of distribution requirements.
3. The AP Program
 4. The IB Program
 5. Other programs
 - a. Alternatives for providing college-level learning in high school
 - i. Collaborative programs between universities or colleges, and high schools
 - ii. College courses taught in high school
 - iii. Dual enrollment
 - iv. Concurrent enrollment
 - v. College-sponsored enrichment programs
 - vi. Specialized schools

- vii. Distance learning
 - viii. Web-based courses
 - b. Enrichment activities
 - i. Internships, mentorships
 - ii. Academic and research competitions
 - iii. Alternative curricula and instructional approaches
6. Learning with understanding: 7 principles
- a. Principled conceptual knowledge. “Learning with understanding is facilitated when new and existing knowledge is structured around the major concepts and principles of the discipline.”
 - i. Content knowledge should be structured around major organizing principles, “big ideas”.
 - ii. Advanced study should propel students towards recognizing “big ideas”.
 - iii. Breadth of coverage and memorization of facts may hinder this.
 - b. Prior knowledge. “Learners use what they already know to construct new understandings.”
 - i. People construct meaning for new ideas by putting it in relation to what they already understand.
 - ii. Students’ existing knowledge has to be engaged, or they might develop different understandings from what was intended.
 - iii. Students will also separate “school knowledge” from experiential knowledge.
 - iv. To be successful in advanced study, the prerequisite knowledge base must be sufficiently broad.
 - v. Opportunities to gain this prerequisite knowledge must be more widespread.
 - c. Metacognition. “Learning is facilitated through the use of metacognition strategies that identify, monitor, and regulate cognitive processes.”
 - i. Students must be able to determine what they already know and what they need to know, to be able to solve problems effectively.
 - ii. Metacognitive ability can be gained through explicit instruction and observing experts as they solve problems.
 - iii. Working on concept maps in small groups on specific content areas seems to be the most effective for providing metacognitive insight.
 - d. Differences among learners. “Learners have different strategies, approaches, patterns of abilities, and learning styles that are a function of the interaction between their heredity and their prior experiences.”
 - i. By high school, students have developed preferences of learning style and pace.
 - ii. Educators should be aware of and try to cater to such differences.
 - iii. Students also need different opportunities to demonstrate their abilities.
 - e. Motivation. “A learner’s motivation to learn and sense of self affects what is learned, how much is learned, and how much effort will be put into the learning process.”
 - i. Motivation affects willingness to learn.

- ii. Motivation is enhanced when the task is perceived to be interesting, meaningful, and sufficiently challenging.
 - iii. Belief that effort is an important factor in success is a strong motivation in advanced courses.
 - iv. A high school culture that emphasizes academics and hard work is very effective.
 - f. Situated learning. “The practices and activities in which people engage while learning to shape what is learned.”
 - i. The culture and context in which something is learned affects the learning process.
 - ii. Limiting the contexts in which a concept appears limits the student’s ability to apply it to situations.
 - iii. Learning must involve applications and take place in the context of authentic activities.
 - 1. Students learn about the conditions for applying knowledge.
 - 2. They are more likely to engage in invention and problem solving in new situations
 - 3. They are able to see the implications of their knowledge
 - 4. Their knowledge is more structured towards its application.
 - g. Learning communities. “Learning is enhanced through socially supported interactions.”
 - i. Interaction and collaboration is good.
 - ii. Students can test ideas against one another and learn from observation.
 - iii. Low-ability classes tend to focus on routines, worksheets and other individual activities.
 - iv. “Substantive conversation” is a powerful strategy.
- 7. Designing curriculum, instruction, assessment and professional development
 - a. Curriculum
 - i. Structure the concepts, content, and procedures around “big ideas”.
 - ii. Link new knowledge to what is already known in a logical and sequential manner.
 - iii. Focus on depth of understanding rather than breadth of content.
 - iv. Include activities that allow students to experience problem solving and use their personal experience.
 - v. Develop students’ abilities to make meaningful applications and generalizations
 - vi. Use language and models which practicing experts use.
 - vii. Emphasize interdisciplinary aspects and help students connect in-class knowledge to outside experience.
 - b. Instruction
 - i. Maintain students’ focus on “big ideas”.
 - ii. Consider what students already know.
 - iii. Detect and address prior misconceptions.
 - iv. Understand differences between students in interests, motivations, preferences, knowledge, abilities.
 - v. Provide appropriate degree of explicitness.

- vi. Recognize students' preferences for different symbol systems, and uses multiple representations of the same content.
 - vii. Engage students in meaningful activities.
 - viii. Encourage students to collaborate, and think and speak like experts.
 - ix. Allow students to conjecture, experiment, and explore.
 - x. Explicitly teach metacognition.
 - xi. Use different formal and informal assessment.
 - xii. Create expectations for students to experience success and develop confidence.
- c. Assessment
- i. Based on a model that best represents how students represent knowledge
 - ii. Considers reliability, validity, and fairness.
 - iii. Aligned with curriculum and instruction.
 - iv. Includes important content and demands full range of cognition.
 - v. Multifaceted and continuous – students also receive continuous feedback.
 - vi. Assesses both qualitative and quantitative understanding, provides multiple methods for student to demonstrate learning.
- d. Teacher professional development
- i. Focus on development of knowledge
 - 1. Subject knowledge – teachers must have deep conceptual understanding themselves.
 - 2. Student knowledge – multiple perspectives on students
 - 3. Subject-specific pedagogical knowledge
 - ii. Treats teachers as active learners – they construct their own understandings.
 - iii. Grounded in practice.
 - iv. Takes place in professional communities – teachers can discuss with colleagues.
 - v. Ongoing, long-term.
8. Analysis of the AP and IB programs based on learning research
- a. Principled conceptual knowledge
- i. Breadth versus depth
 - 1. Too much content
 - a. Insufficient time, only superficial coverage of some areas
 - b. Too much emphasis on memorization of disconnected facts
 - 2. Assessments emphasize recall of facts
 - ii. Organizing complex content
 - 1. Teachers not given enough guidance.
 - 2. Students probably unable to organize large volume of content by themselves.
 - iii. Examinations and conceptual learning
 - 1. Solving specific problem types rather than modeling and problem-solving in general.
 - 2. Emphasis on procedural solving.

- b. Prior knowledge
 - i. Prerequisites
 - 1. Difficult to ensure that students have met prerequisites.
 - 2. Clearer and more detailed articulation of necessary prior knowledge is needed.
 - ii. Coordination of Courses
 - 1. Greater coordination needed in more basic classes.
 - 2. Essential if AP is seen as extension of high school.
 - iii. Implications of prior knowledge
 - 1. No guidance provided on sequence of topics.
 - 2. Less experienced teachers may cover too much.
 - iv. Misconceptions and formative assessment
 - 1. Teachers could be provided with information about common student misconceptions.
 - 2. Items could be included in the assessments which address misconceptions.
- c. Metacognition
 - i. Advanced study is a significant opportunity to provide instruction in metacognition.
 - ii. Little attention paid to this.
 - iii. More emphasis needed on making thinking process visible.
- d. Differences among learners
 - i. Should build variability into curricula
 - ii. Provide more students with best-suited learning environments.
 - iii. Using differences in assessment
 - 1. Both IB and AP scores can show more detail about how much the student knows about how many topics.
 - 2. Should use different assessment means over a period of time.
- e. Motivation
 - i. Believing in the possibility of success
 - 1. Students must believe that they can succeed. Programs such as Vertical Teams, etc help students towards this.
 - ii. Deciding to enroll in an advanced course
 - 1. Students want to challenge themselves academically
 - 2. Extrinsic rewards – college credit, etc.
 - iii. Investing effort for success
 - 1. Educational programs should be designed in accordance with the principles of learning.
 - 2. Computers, teachers and peers are integrated as learning partners.
 - iv. The final examination
 - 1. More IB than AP students sit for the final exam. In IB, the exam is seen as an integral part of the course and the best way to demonstrate what they have learnt.
- f. Learning communities
 - i. Lecture format is used extensively
 - 1. Efficient for information transmission

- 2. Not for identifying misconceptions, practice skills, or receive feedback.
 - ii. Short lab periods mean less time for collaboration.
 - g. Learning in context
 - i. Assessments do not measure application of principles in unfamiliar contexts.
 - ii. AP does not encourage interdisciplinary work.
 - iii. Laboratories tend to be “cookbook” style.
- 9. Analysis of AP and IB curriculum, instruction, assessment and professional development
 - a. Curriculum
 - i. Depth versus breadth: Still too broad to “study topics in sufficient breadth to develop deep conceptual understanding.”
 - ii. Curriculum development: AP courses tend to be as similar to the “average” introductory college class. This is unsatisfactory for deep conceptual understanding.
 - iii. Variability: Due to large variability across schools, it is difficult to ascertain how much has been learnt by the students.
 - b. Instruction
 - i. Worthwhile tasks: Difficult to select and develop worthwhile problems which can develop conceptual understanding.
 - ii. Promotion of high-quality instruction: Time is the single most important factor; teachers need time to keep up with changes in the subject and pedagogy, to prepare for and grade classes, and so on.
 - c. Assessment
 - i. Examination design and development
 - 1. AP exams are designed by both subject matter and psychometry experts.
 - 2. IB exams depend more on teachers.
 - ii. Support for inferences drawn from assessment results
 - 1. While content coverage is adequate, there is no data about whether the tests measure important cognitive skills.
 - 2. Neither program has information about what the tests actually measure.
 - iii. Consequential variability of AP and IB assessments
 - 1. Very little evidence available.
 - 2. Concerns over large numbers of students entering college with AP credit.
 - 3. Concerns over equity – does the assessment produce inequity?
 - d. Professional development
 - i. Teachers need well-designed and ongoing professional development.
 - ii. Neither program has sustained or mandatory professional development programs.
 - iii. Very few opportunities for teachers to interact
 - 1. In some schools, they may be the only ones teaching advanced classes.

10. Uses, misuses and unintended consequences of AP and IB

a. High Stakes

i. Effects on students

1. Students may be discouraged from taking classes if teachers feel they may not do well.

ii. Effects on teaching and learning

1. Teachers are more likely to teach students to “game” the test.
2. A large body of knowledge is covered superficially.
3. Laboratory experiences are ignored.
4. Students feel a disconnect from the real world.

iii. Effects on teachers

1. Danger of judging teachers by how well their class performs.

iv. Effects on schools

1. Ranking schools by number of AP/IB tests taken

- a. Penalizes schools with different educational values or priorities.
- b. Does not address issue of whether students are adequately prepared for advanced study.

2. Evaluating school quality by the numbers

- a. Students’ academic achievements may come from factors other than school quality, so judging a school based simply on test scores is not an accurate reflection.

b. Quality control

i. Standards and regulation of courses

1. Schools cannot offer IB classes without the IBO’s certification.
2. However, AP has no such regulation. Schools can put an AP label on a non-AP class or institute AP classes without the necessary facilities or human resource.

ii. Curriculum compression

1. Basic classes are rushed through to provide more time for advanced study.
2. Dangerous due to the hierarchical and cumulative nature of math and science.

iii. Participation in examinations

1. While all IB students are expected to take the exams, this is not the case for AP.
2. The College Board has little to no feedback on the quality of AP classes.

iv. Online courses

1. AP courses and professional development programs may be distributed online.
2. Lack of laboratory experience is the main concern.

c. Access and equity

i. Limiting students’ access to AP and IB

1. Competitive high schools allow only a select group into AP courses.
2. Probably to influence overall pass rate and gain flak with colleges.
3. Even though AP and IB are not appropriate for all students, there are few rigorous options outside these.
- ii. Prerequisites
 1. Ranges from open admission to very restrictive criteria.
 2. Schools need to demonstrate that their prerequisites are valid predictors of student success.
- d. College credit and placement
 - i. AP Program
 1. Unclear whether AP students had any advantage (or disadvantage) in second-level college classes
 - ii. IB Program
 1. IB classes are not designed to resemble college classes, so advanced placement on the basis of IB does not merit a clear advantage.
 - iii. Advanced placement on an individual basis is recommended.

11. Recommendations

- a. The primary goal of advanced study: deep conceptual understanding.
 - i. Acceleration to college-level material in itself is not sufficient.
- b. Access and equity
 - i. Schools need to find ways to integrate advanced study with the rest of the program
 - ii. The plan needs to be coherent from middle school onwards.
 - iii. High schools should eliminate low-level “dead-end” classes.
- c. Learning principles
 - i. Based on scientific studies on how people learn.
- d. Curriculum
 - i. Depth over breadth.
 - ii. Focus on “big ideas”.
 - iii. Stay abreast of current developments in the field.
 - iv. Requires team of experienced teachers working with experts in the discipline, cognition, and pedagogy.
- e. Instruction
 - i. Engage students in inquiry
 1. Provide opportunities to experiment and conjecture
 2. Analyze information
 3. Solve problems individually and in groups
 - ii. Recognize differences between learners
 1. Use multiple representations of ideas
 2. Use a variety of tasks
- f. Assessment
 - i. Frequent formative assessment
 1. To guide instruction and monitor learning
 - ii. Final exam’s purpose is to certify mastery.
 - iii. Include content and evaluate depth of understanding

- g. Qualified teachers and professional development
 - i. Provide frequent opportunities for professional development
 - 1. Teachers can improve their knowledge of content and pedagogy.
 - ii. Clearly specify and monitor qualifications of teachers
 - iii. Professional development must be adequately funded and ongoing.
- h. Alternative programs
 - i. Alternatives should be developed and evaluated.
 - ii. Increase opportunity for those without access to AP or IB courses.
- i. The secondary-college interface
 - i. Advanced placement in college should be based on individual assessment of students rather than depending on AP.
 - ii. The criticisms in this report also apply to introductory college classes. Teachers' ideas about how to teach science and math come from their college experiences. So similar changes should be made.
- j. Changes in the AP and IB programs
 - i. Not replicate introductory college courses
 - ii. Measure conceptual understanding and complex reasoning
 - iii. Take responsibility for instructional approaches
 - iv. Greater quality control
 - v. Provide assistance to schools
 - vi. Offer guidance to educators, policymakers, and public
 - vii. Do own research on implementation