

## Learning and Understanding: implications for Math and Science Education – Jerry Gollub

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- In this talk, I will discuss a set of research based principles to further learning with understanding, and the application of these principles for instruction, curriculum design and assessment.
- In a 2002 report, a study committee of the National Research Council that I co-chaired used these principles to evaluate the AP and IB programs in mathematics and science.

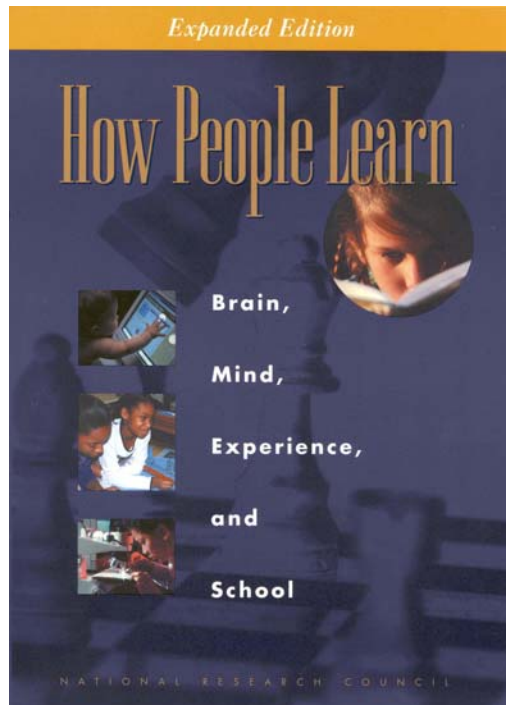
# The National Academy of Sciences

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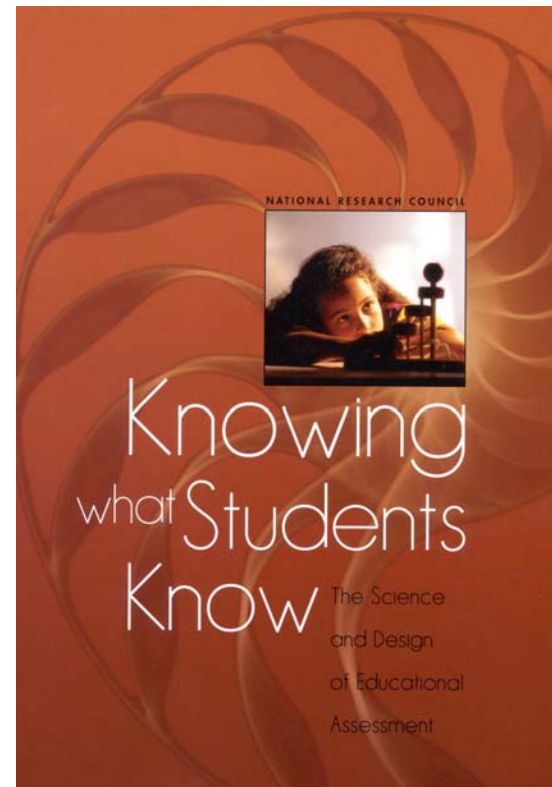
- Created by Congress to advise the nation.
- Consists of about 1000 scientists elected on the basis of research achievement.
- It's research arm, the National Research Council, conducts studies upon request by any agency of the government.
- Those conducting a study (not necessarily members) are selected for their relevant expertise; public comment.
- Several hundred investigations are conducted annually; extremely diverse (see partial current list).
- Study committees work by consensus (usually).
- Rigorous standards of peer review.

# National Academy Reports on Learning (CD)

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<http://www.nap.edu/catalog/9853.html>



<http://www.nap.edu/catalog/10019.html>

# How People Learn: Experts vs. Novices

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1. Experts notice features and meaningful patterns of information that are not noticed by novices.
2. Experts have acquired a great deal of content knowledge that is organized in ways that reflect a deep understanding of their subject matter.
3. Experts' knowledge cannot be reduced to sets of isolated facts or propositions but, instead, reflects contexts of applicability: that is, the knowledge is "conditionalized" on a set of circumstances.
4. Experts are able to flexibly retrieve important aspects of their knowledge with little attentional effort.
5. Though experts know their disciplines thoroughly, this does not guarantee that they are able to teach others.
6. Experts have varying levels of flexibility in their approach to new situations.

# How People Learn – Organization of Knowledge

## BOX 2.2 What Expert and Novice Teachers Notice

Expert and novice teachers notice very different things when viewing a videotape of a classroom lesson.

Expert 6: On the left monitor, the students' note taking indicates that they have seen sheets like this and have had presentations like this before; it's fairly efficient at this point because they're used to the format they are using.

Expert 7: I don't understand why the students can't be finding out this information on their own rather than listening to someone tell them because if you watch the faces of most of them, they start out for about the first 2 or 3 minutes sort of paying attention to what's going on and then just drift off.

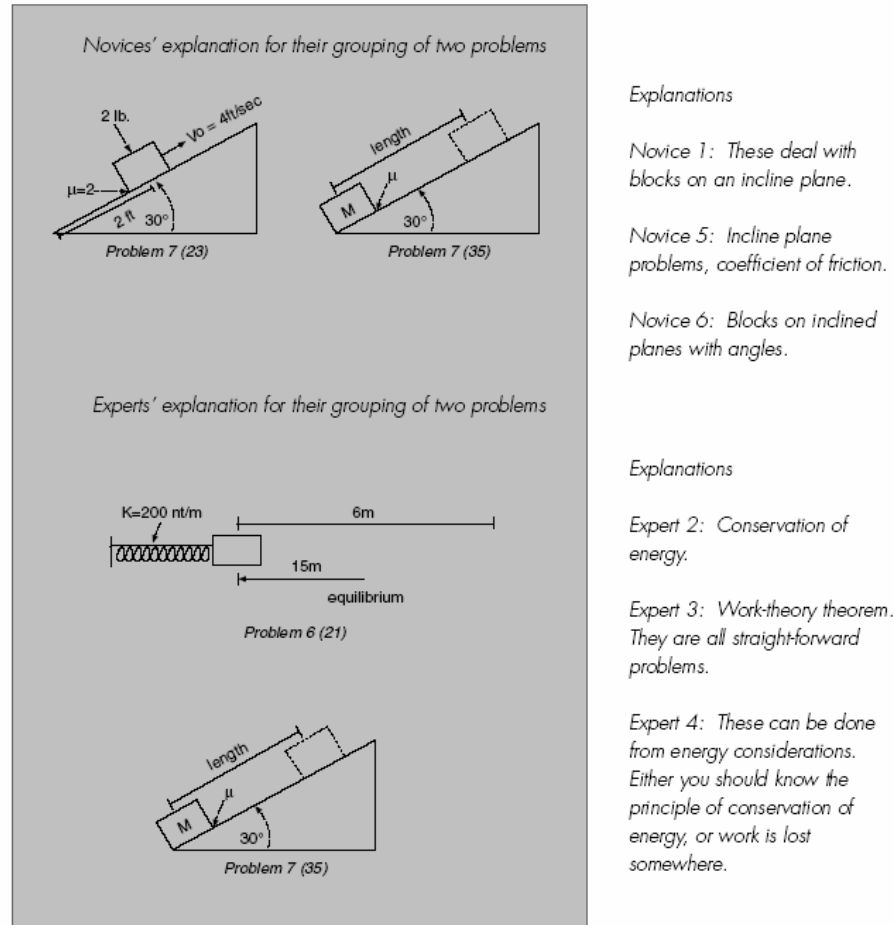
Expert 2: . . . I haven't heard a bell, but the students are already at their desks and seem to be doing purposeful activity, and this is about the time that I decide they must be an accelerated group because they came into the room and started something rather than just sitting down and socializing.

Novice 1: . . . I can't tell what they are doing. They're getting ready for class, but I can't tell what they're doing.

Novice 3: She's trying to communicate with them here about something, but I sure couldn't tell what it was.

Another novice: It's a lot to watch.

# Organizing Principles



**FIGURE 2.4** An example of sortings of physics problems made by novices and experts. Each picture above represents a diagram that can be drawn from the storyline of a physics problem taken from an introductory physics textbook. The novices and experts in this study were asked to categorize many such problems based on similarity of solution. The two pairs show a marked contrast in the experts' and novices' categorization schemes. Novices tend to categorize physics problems as being solved similarly if they "look the same" (that is, share the same surface features), whereas experts categorize according to the major principle that could be applied to solve the problems.  
 SOURCE: Adapted from Chi et al. (1981).

# Transferability of Learning

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- Transferability requires mastery of a subject; this takes much more time than is usually available in a classroom setting.
- A focus on organizing principles and abstract representations (not only particular contexts) facilitates transfer.
- Learning new content requires transfer of prior knowledge.

# Seven Learning Principles (1)

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- What do we know from research on learning and thinking??
  1. Learning is facilitated when knowledge is structured around major concepts and principles.
  2. The learner's prior knowledge is the starting point for effective learning.
  3. Metacognitive learning (self-monitoring) is important for acquiring proficiency.
  4. Recognizing differences among learners is important for effective teaching and learning.

## Seven Learning Principles (cont.)

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5. Learners' beliefs about their ability to learn affect their success.
6. Context of learning (practices and activities) shapes what is learned.
7. Socially supported interactions strengthen learning.

# Key Elements of Educational Systems

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- Curriculum
- Instruction
- Assessment
- Teacher professional development

## Curriculum that promotes understanding:

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- Is structured around organizing principles of the subject.
- Links new knowledge to what students already know; logically sequenced.
- Focuses on depth of understanding rather than breadth of coverage; many contexts.
- Includes learning activities that allow students to experience problem solving and inquiry in varied contexts.
- Models real science and mathematics.

## Teaching that promotes understanding:

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- Reflects differences among students.
- Structures learning situations in which students can sometimes work collaboratively.
- Encourages classroom discourse so that students can make conjectures, present solutions, and argue about the validity of claims.
- Includes explicit instruction in metacognition.
- Monitors the development of understanding regularly.
- Develops confidence.

## Assessment that promotes understanding:

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- Is ongoing so that students can monitor their own learning.
- Evaluates reasoning.
- Involves students in developing assessment tools and analyzing the results.
- Includes classroom discourse on what is understood and what is not.

## Effective professional development:

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- Focuses on teachers' knowledge of (a) content; (b) students as learners; (c) subject specific pedagogy.
- Treats teachers as active learners who build on existing knowledge.
- Takes place in professional communities where teachers can discuss and collaborate.
- Spans teachers' professional lives.

# Improving Advanced Study of Mathematics and Science in U.S. High Schools

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- 2-year study by the **National Research Council**, Center for Education.
- Stimulated initially by TIMSS international comparisons.
- Focused on AP and IB programs in **Biology, Chemistry, Physics, Math**.
- Considers programs in light of research on **learning and cognition**.
- Limited consideration of alternatives.
- Committee: scientist-researchers, teachers, educators with experience in teacher education and access/equity, cognitive scientists.
- Supported by **NCFE Dept. of Education**

## Committee Members

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- Jerry Gollub, Physics, Haverford/Penn (Co-Chair)
- Philip Curtis, Math, UCLA (Co-Chair)
- Camilla Benbow, Education, Vanderbilt
- Hilda Borko, Education, UC Boulder
- Wanda Bussy, IB Math Teacher
- Glenn Crosby, Chemistry, Washington State
- John Dossey, Mathematics, Illinois State
- David Ely, AP Biology Teacher
- J.K. Haynes, Biology, Morehouse
- Deborah Hughes Hallett, Mathematics, U. Arizona
- Valerie Lee, Education, Michigan

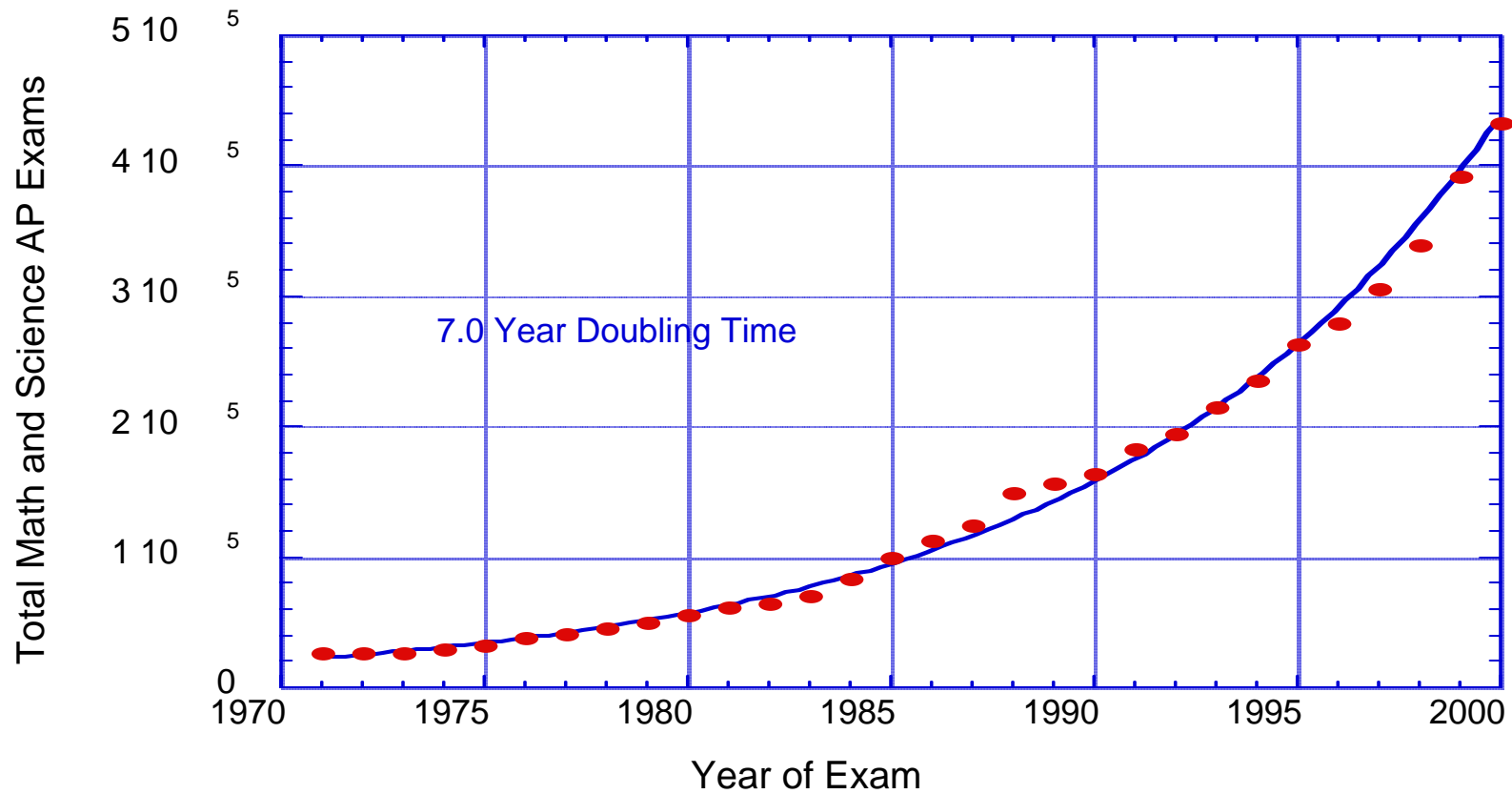
## Committee (cont.) and Staff

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- Stephanie Pace Marshall, President Illinois Math and Science Academy
- Michael Martinez, Education, U.C. Irvine
- Patsy Mueller, AP Chemistry Teacher
- Joseph Novak, education, Cornell and U.W. FL
- Jeannie Oakes, GSE, UCLA
- Robin Spital, AP Physics Teacher
- Conrad Stanitski, Chemistry, U. Central AK
- William Wood, Biology, U. Colorado Boulder

NRC STAFF: Jay Labov (Director); Meryl Bertenthal (Sr. Program Officer);

# Growth of Math/Science AP



# The AP Program

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- Developed by the College Board.
- 11 courses in 8 science/math subjects.
- Course outlines based on college surveys.
- Limited specific advice to teachers. Actual courses vary widely.
- A survey of the preparation and experience of teachers is under way.
- Elective, end-of-course exams; 1-5 scale; 34% do not take the exams.

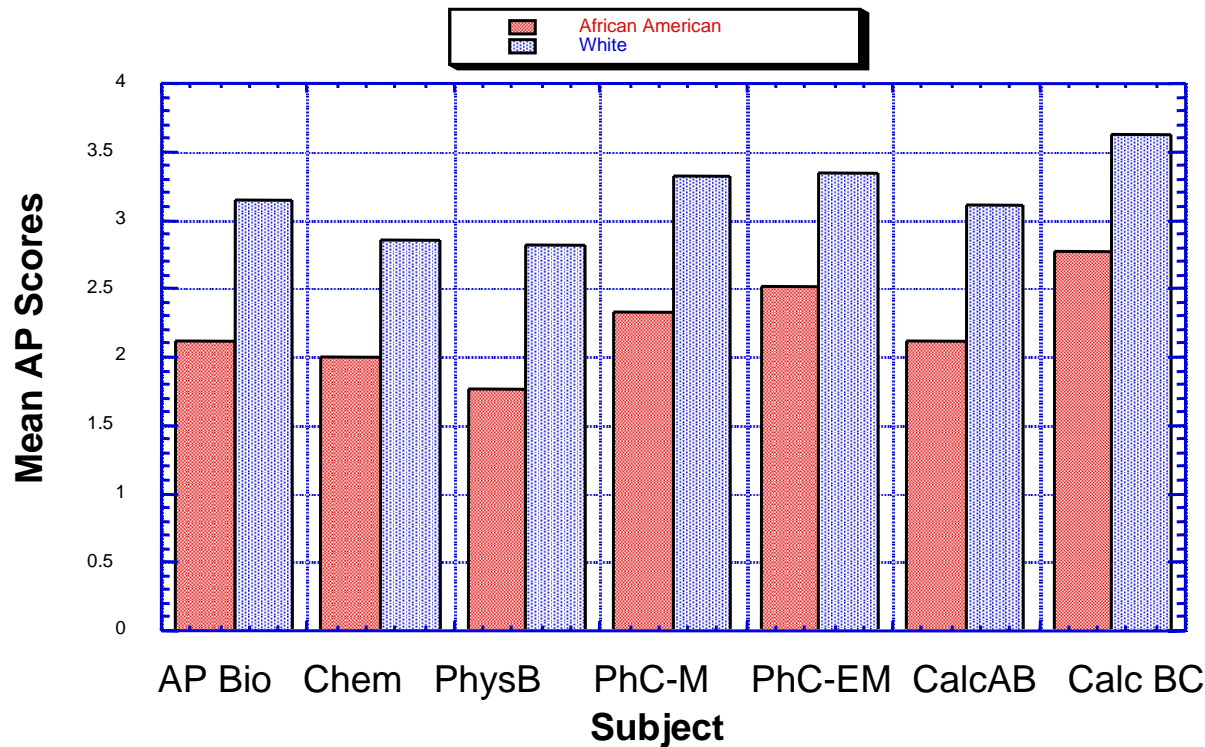
## What is driving this growth?

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- Pressure to provide credentials for admission to selective colleges and universities.
- AP courses are sometimes used to measure school quality.
- Hopes of faster progress in college, and cost savings.

# Minority Participation and Success in AP

- Number of AP courses offered in schools declines as African-American and Hispanic population increases. (CA)
- These groups under-participate by factor of 3-4 nationally.



# Example of Analysis of Programs based on Learning Principles

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- **Role of Prior Knowledge:**

- » Prerequisites: Neither the CB nor IBO specify the competencies students need prior to advanced study.
- » Inadequate preparation of students starting in middle school.
- » Inadequate attention to sequencing topics within courses for gradually increasing complexity.
- » Inadequate attention to diagnosing and correcting common misconceptions.

# Example of Analysis of Programs based on Learning Principles

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- **Situated Learning:**

- » AP and IB programs do not emphasize interdisciplinary connections.
- » AP Program does not assess ability to apply learning to new situations.
- » Inadequate use of inquiry based laboratory experiences, or use of local science-related resources.

# A Framework for Evaluating Programs

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- Systematic design of four program elements based on learning principles is required for successful programs: curriculum, instruction, assessment, and professional development of teachers.
  - » Effective **curricula** in math and science are coherent, focussed on important ideas, and sequenced to optimize learning.
  - » **Instruction** begins with careful consideration of students thinking.
  - » **Assessment** includes both process and content, aligned with instruction and desired outcomes.
- The Committee used this framework for evaluation

## Subject Reports: Common Elements

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- Inadequate utilization of learning research. Programs not consistent with national standards; excessive content encourages memorization rather than conceptual learning. Insufficient interdisciplinary connections in AP.
- Exams do not test conceptual understanding adequately.
- Clear expectations for teacher and student preparation are needed.
- Insufficient cooperation across levels of the educational system.

# Misuses of AP and IB Exams in Ranking Schools and Evaluating Teachers

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- Counter to AERA Standards for Testing because uncontrolled for prior knowledge.
- May cause teachers to discourage students from taking courses or exams.
- Motivates teachers to teach to tests that are flawed.
- Prevents schools from offering other rigorous options.
- Emphasizing enrollment numbers can lead to inadequate preparation of students.

## The Full Report:

<http://www.nap.edu/catalog/10129.html>

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- Explains how programs fit within the context of high schools; relationship to middle school and higher education.
- Describes AP, IB, and alternatives in depth.
- Reviews research on learning and its application to these programs.
- Analyzes AP and IB programs for consistency with this research.
- Describes misuses of these programs.
- Presents recommendations for change.
- Includes panel reports on Biology, Chemistry, Physics, and Mathematics (web only).

END



# Curriculum

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- Curricula for advanced study should focus on a reasonable number of central organizing concepts and principles and their empirical basis.
- Integration with earlier courses. Multiple year programs may help.
- Requires collaborative team effort: teachers, scientists, experts in pedagogy. Repeated cycles of design and revision.

# Instruction

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- Engage students in inquiry via opportunities to experiment, analyze, make conjectures argue, and solve problems.
- Instruction: recognize differences among learners; employ multiple representations of ideas; pose a variety of tasks.
- *Program developers* should suggest appropriate strategies to teachers. Current materials provide little assistance.

## Assessment: During and After

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- Assessment should include content and process.
- Final assessments influence instruction, so they need to measure what is important.
- Avoid predictable formulaic questions; test conceptual understanding and thinking.
- Need for research about what the examinations measure.
- Teachers need assistance with with in-course assessments for practice and feedback.
- Reporting: A single numerical score is not sufficiently informative.

# Teachers and Prof. Development

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- AP and IB should specify the qualifications expected of teachers.
- Schools must provide frequent opportunities for continuing professional development.
- AP and IB should provide models of PD that foster quality instruction.
- PD should emphasize deep understanding of content and **subject-specific** methods of inquiry.
- Teachers need professional communities.
- *University science and mathematics departments can help.*