INNOVATIONS IN EDUCATION AND CLINICAL PRACTICE

# Educational Innovations in Academic Medicine and Environmental Trends

*David M. Irby, PhD, LuAnn Wilkerson, EdD*

**Fifteen educational innovations in academic medicine are described in relation to 5 environmental trends. The first trend, demands for increased clinical productivity, has diminished the learning environment, necessitating new organizational structures to support teaching, such as academies of medical educators, mission-based management, and faculty development. The second trend is multidisciplinary approaches to science and education. This is stimulating the growth of multidisciplinary curricular design and oversight along with integrated curricular structures. Third, the science of learning advocates the use of case-based, active learning methods; learning communities such as societies and colleges; and instructional technology. Fourth, shifting views of health and disease are encouraging the addition of new content in the curriculum. In response, theme committees are weaving content across the curriculum, new courses are being inserted into curricula, and community-based education is providing learning experiences outside of academic medical centers. Fifth, calls for accountability are leading to new forms of performance assessment using objective structured clinical exams, clinical examination exercises, simulators, and comprehensive assessment programs. These innovations are transforming medical education.**

***KEY WORDS:*** **educational innovations; environmental trends.**
**J GEN INTERN MED 2003;18:370–376.**

Innovation has been part of the medical education landscape since the Flexner report, although it has been largely confined to new medical schools and to small activities in a single course or clerkship.[1] However, in the past decade almost every medical school in North America has embarked on some type of curricular change and/or educational innovation.[2,3] Remarkable changes include new content, innovative instructional methods, new curricular structures, and creative approaches to assessment.

*Received from the Office of Medical Education and Department of Medicine (DMI), University of California–San Francisco, San Francisco, Calif; and Center for Educational Development and Research, David Geffen School of Medicine (LAW), University of California–Los Angeles, Los Angeles, Calif.*

*Address correspondence and requests for reprints to Dr. Irby: Office of Medical Education, School of Medicine, University of California–San Francisco, 521 Parnassus Ave., Room C-254, San Francisco, CA 94143-0410 (e-mail: irby@medsch.ucsf.edu).*

We argue that the scope of innovation has been accelerated, although not always caused by, 5 environmental trends that are changing the face of medical education, making new ways of teaching and learning both necessary and possible. These trends include pressures for increased clinical productivity through managed care, the development of a multidisciplinary culture among researchers and health professionals, the emergence of a new science of learning and enabling technologies, changes in health care needs of a diverse populace, and demands for accountability. These 5 forces are briefly described along with associated innovations in medical education.

The relationship between environmental trends and educational innovations described in this article vary from causally to logically associated. Our intent is to highlight innovative exemplars, not to provide an exhaustive inventory or to present an evidence-based assessment of these innovations. While not providing a comprehensive discussion of the forces and trends, we will direct the reader to published resources for more in-depth information. Being selective and illustrative in our choice of innovations, we have vastly underrepresented the number of schools involved and the diversity of the reform.

## TREND 1. MANAGED CARE AND THE NEED TO RECAPTURE THE EDUCATIONAL MISSION

Over the past decade, industry and government have sought to reduce the cost of medical care by decreasing reimbursements to hospitals and health care providers. Managed care was viewed as the vehicle for achieving this goal. The impact of managed care, the loss of ability to cost shift, and the inherently more expensive operation of academic medical centers[4–6] have resulted in difficult financial times for medical education.

These difficulties are compounded by the rising demands on faculty to increase their own clinical productivity, document care provided, increase supervision of trainees, and reduce resident work hours. Teaching—a time-intensive and largely unsponsored activity—has been slowly crowded out of the schedules of both full-time and voluntary medical school faculty members. Ludmerer, in *Time to Heal*,[7] suggests that the net result of this situation is the erosion of the learning environment in academic medical centers and the return to the nineteenth-century proprietary hospital model of medical education, in which

hospitals rather than universities set the values, directions, and policies in medical education. According to Ludmerer, "Present-day market forces are rapidly destroying the learning environment of clinical education."[8]

In an attempt to recapture the educational mission, some medical schools have developed new organizational structures to support teachers, created greater alignment of resource allocations to academic missions, and invested in faculty development in order to maintain job satisfaction and increase teacher effectiveness.

### Academies of Medical Educators

The University of California–San Francisco and then Harvard Medical School have developed academies of medical educators. The Academy is an interdepartmental network of master teachers that supports teachers, curricular innovations, faculty development, and mentoring of junior faculty members. The Academy fosters cross-departmental collaboration that overcomes departmental isolation. At both schools, members are selected for being outstanding teachers, curriculum developers, educational leaders, mentors, and educational scholars. Institutional resources are used to provide salary support, faculty scholarships, innovations funding, and endowed chairs for teachers.[6,9,10] Other schools, such as Mayo and Baylor, have identified and supported a core teaching faculty. In each instance, the critical feature is the development of a clear organizational structure that supports the time and effort of those faculty members who are central to the educational mission of the institution. Such organizational structures counterbalance the stronger missions of research and patient care,[11] and represent a fundamental departure from past efforts to improve the status of teaching in academic medicine.

### Mission-based Management

Another approach to recapturing the educational mission has been the use of mission-based management to bring into alignment the goals and financial resources of the institution.[12–14] Mission-based management typically involves the development of a metric for assessing the various contributions that faculty members make to the multiple missions of the university. For education, this involves defining each type of educational contribution and assigning weights based upon effort and quality. Resources are then allocated to the various missions based upon performance. The process makes visible and transparent how resources are expended, and directly connects teaching with those resources.

### Faculty Development Programs

Medical schools are investing in a wide range of faculty development programs to boost the morale and sustain the academic careers of their faculty.[15,16] Programs include new faculty orientation programs, mentoring for junior faculty, teaching skill workshops, 1- to 2-year faculty development and leadership development fellowship programs, plus policies and procedures that reward teaching as part of faculty promotion processes.[17–19] In addition, the Stanford Faculty Development Program[20,21] and Harvard-Macy Institutes provide regular courses designed to develop educational leaders who are both skilled teachers and curriculum planners.

## TREND 2. MULTIDISCIPLINARY PERSPECTIVES AND THE NEED FOR INTEGRATIVE STRUCTURES

Scientific investigation and health care practice increasingly require the integration of multiple disciplines to more fully represent "new ways of thinking about human health and disease in the emerging age of molecular and cellular medicine."[22] With the growing predominance of molecular and genetic research, new faculty and new research units have appeared in most medical schools.

The multidisciplinary culture of research is spilling over into medical education with school-wide curriculum oversight and creation of learning objectives along with the proliferation of integrated curricula. While these integrative perspectives may have been the exception in the past, they have become increasingly the norm.

### Multidisciplinary Perspectives on Curriculum Objectives

The Association of American Medical Colleges created the Medical School Objectives Project to guide medical schools in designing their own objectives and the Liaison Committee on Medical Education in accrediting medical schools.[23] On campus, interdisciplinary curriculum committees provide oversight of educational programs, helping to balance the special interests of departments and specialty organizations.[2]

At the graduate medical education level, the Accreditation Council for Graduate Medical Education has broken the barrier of disciplinary boundaries to establish core competencies for all of graduate medical education. Six core competencies now guide residency curriculum and outcome assessment: patient care, knowledge, practice-based learning and improvement, interpersonal communication skills, professionalism, and systems-based practice. Curricula based on these shared competencies reflect the growing interdisciplinary nature of our institutions.

### Integrative Curriculum

New integrative curricular structures are proliferating in the form of multidisciplinary block courses in the basic sciences, blended clerkships (combining 2 or more specialties into 1 clinical experience), and integrated clinical experiences in multidisciplinary health care settings.[24]

Although many medical schools have adopted the organ system curriculum model for teaching pathophysiology in the second year, most have retained departmentally

based basic science courses taught in a concurrent fashion during the first year. A growing number of schools have redesigned all of preclinical education into larger integrated blocks with titles such as *Organs; Metabolism; Life Cycle; Mind, Brain, and Behavior*. Block courses often combine normal and abnormal biology.

Integrative clinical experiences that emphasize the interdependence of various specialties and health care providers are on the rise. In a 2-week Beginning-to-End Rotation at the University of Connecticut just prior to the inpatient medicine clerkship, students focus on the patient's experience of hospitalization from a multidisciplinary perspective.[25] Each student follows 3 to 7 patients per week from the emergency department through hospitalization, treatment, discharge and rehabilitation.

## TREND 3. NEW SCIENCE OF LEARNING, TECHNOLOGY AND INSTRUCTIONAL INNOVATIONS

In a recent review of research conducted by the National Research Council of the National Academy of Sciences,[26] a panel of experts concluded that evidence from numerous branches of science converge in support of a new theory of learning. The emerging view is of learning as an active, constructive, social, and self-reflective process.[27] Learners construct a unique mental representation of the material to be learned, select information perceived to be relevant, and interpret that information on the basis of preexisting knowledge and current needs. Substantive learning occurs in periods of confusion and surprise, and during discussions in which understandings are challenged. Learning is monitored and controlled by the learner.

These basic research findings on learning suggest the need for educational environments that are learner-centered and knowledge-rich, guided by assessment, and situated in a community of learners.[28] In medical education, educational programs increasingly include case-based or problem-based learning and other small-group instructional models, collaborative organizations to support student-faculty interactions, and technology-enhanced educational tools.[24]

### Small-group, Case-based Learning

Learning in small groups facilitates the development of students' cognitive processes through their engagement in the active construction of meaning and socially negotiated understanding. In small-group discussion, students are encouraged to articulate what they know and don't know, challenge their assumptions, wrestle with the limits of their understanding, determine how to frame and ask questions, decide what information is needed to answer the questions, and think about how to use and apply what they have already learned. A meta-analysis of 39 studies of small-group learning in university science courses demonstrated consistent and robust effects of small-group learning on achievement, persistence, and attitude.[29] Eighty percent of medical schools report using small-group instruction.[2] The long-term outcomes study comparing the New Pathway Program with the traditional curriculum at Harvard Medical School suggests that students from traditional and problem-based instruction are more alike than different. However, New Pathway students' ratings were significantly higher for their preparedness to practice humanistic medicine, the influence of faculty in the first 2 years on their thinking, and satisfaction with pedagogical methods.[30]

Much of recent curriculum reform in medical student education has been fueled by the belief that learning is enhanced by students' working on content in the context of clinical cases. In problem-based learning, the successive disclosure of case material is coupled with a period of self-directed study and repeated small-group discussion for purposes of stimulating students' knowledge acquisition, application, and learning skills.[31–34] Other case-based approaches employ a single discussion period using complex case studies, clinical problem sets, or a sequential case presentation that require students to apply what they have learned through advanced reading, concurrent class work, or clinical experience to the understanding and resolution of the case. All medical schools described their curricula in terms of active learning methods.[2] In addition, 57% reported using problem-based learning. Small-group, case-based learning continues to be the area of greatest change in medical school curricula.

### Learning Communities

Seeking to strengthen mentoring, career advising, and longitudinal relationships between students and faculty members, many medical schools are creating clusters of students and faculty that work together across multiple years of the curriculum. At Harvard, societies are composed of random groupings of students on entry to medical school and a selected group of faculty under the guidance of a Master. The Societies have curricular as well as social and advising responsibilities. Other schools use advisory colleges to provide students with mentoring and advising services.

At the University of California–Los Angeles, academic colleges have been implemented to help students make better educational use of the fourth year of the curriculum and to strengthen career advising and mentoring. The colleges are composed of faculty and students who share general career interests: Primary Care, Applied Anatomy, Acute Care, Medical Science, Urban Underserved, and MD/MBA. The colleges begin with an introductory block focused on clinical decision making and skills, followed by a year-long program of seminars, recommended electives, a longitudinal project, and career advising.

### Instructional Technology

Advances in technology have made possible an increased use of simulations to support learning.[35]

Technological simulations connect learners with real-world problems, provide tools to increase practice opportunities, and expand access to individual feedback and reflection.[26] Numerous simulations have been crafted from the National Library of Medicine's Visible Human Project. Procedural skills, perceptual interpretation, and clinical knowledge are being enhanced through interaction with technologically enriched simulators, from full-body mannequins to virtual reality programs.[36,37] Clinical judgment is the focus of patient care multimedia simulations such as the American College of Physicians on-line cases that offer students the chance for repeated practice in a safe environment coupled with opportunities for individualized and immediate feedback.[38]

Technology has also created the concept of "just-in-time" education with Internet access to an ever increasing number of easily searchable bodies of published research and expert knowledge as portable as the latest PDA.[39] Web courseware and web databases have been developed to provide access to curricular and instructional information, on-line discussion groups, administrative policies, and library resources.[40] Computer-based instruction is used by 65% of medical schools, and computer-based evaluation is used by 37%.[2] With knowledge so easily accessible, physicians-in-training as well as practicing physicians can depend less upon their own memories and more upon external memory devices.

## TREND 4. SHIFTING VIEWS OF HEALTH AND DISEASE AND NEED FOR A RESPONSIVE CURRICULUM

The practice of medicine and the medical curriculum are constantly being reshaped by changing community needs and the interplay of scientific, social, and economic forces. For example, the Human Genome Project is contributing new understandings of the risk of diseases and providing glimpses into a future of genetically engineered drugs and tissues.[41] *Healthy People 2010*, the federal government's goals for improving the nation's health, calls for a model of health that integrates findings from both biomedical and public health research.[42] Patients expect their physicians to be skilled in managing an ever-enlarging set of problems—chronic disease, complementary medicine, pain management, end-of-life care, bioterrorism—and to be effective in communicating and providing compassionate care.

In response to this changing view of health and disease, medical schools are struggling to insert new perspectives while prioritizing traditional content.[24] This struggle is made more complex as professional associations call for more comprehensive objectives for medical student education in these new areas.[23,43–46]

### Weaving Themes across the Curriculum

In seeking to find the time for new curricular content, many medical schools have chosen to weave new themes vertically through required courses to create a strong and integrated fabric.[47] Theme committees coordinate teaching of their content across courses and negotiate with course and clerkship directors to insert material into the core curriculum.

### Carving Out Intensive Blocks of Time

New content is also being inserted into the curriculum by carving out short blocks of time in which a theme can be addressed. In order to weave community health into its curriculum, Wake Forest instituted immersion weeks spread over the first 2 years, in which students leave campus to spend time in the community. During these periods, students participate in the office practice of a primary care preceptor and conduct a community project that involves the identification of a community health problem and development of a prescription for addressing that problem.[3]

Other schools have created longitudinal courses that continue across the core clerkship period, often focusing on the patient-doctor relationship and other "orphan" topics such as health care economics, ethics, public health, or professional development.[48]

### Community-based Education

Many medical schools have a strong mission of serving their communities. These include community-based medical schools such as the University of New Mexico and East Carolina University, as well as regional medical schools such as the University of Washington and the University of North Carolina. The University of Rochester has established a compact with the city of Rochester to promote optimal health of the populace. Medical schools have oriented their undergraduate curricula around the predominant health problems of their region, promoted student involvement in health projects, and established close working relationship with community physicians and agencies.[49,50]

## TREND 5. ACCOUNTABILITY AND NEW ASSESSMENT TECHNOLOGIES

The public is increasingly demanding accountability from its educational and governmental institutions. In line with this trend, accreditation bodies are shifting their focus from evaluation of program process to outcomes. Licensure and recertification examinations are shifting from simple knowledge assessment to competency assessment (testing for integrative and adaptive clinical knowledge and skills).

Concerns over patient safety have also contributed to demands for accountability. Errors in medicine were largely swept under the rug until the landmark study at the Harvard School of Public Health[51] and the publication of the recent Institute of Medicine report *To Err Is Human*.[52,53] New tools developed through educational research and quality improvement efforts have made it possible for medical schools to do a better job of evaluating educational processes and outcomes.[54]

### Objective Structured Clinical Exam

The most common performance-based examination being used in medical education today is the Objective Structured Clinical Examination, in which individual assessment stations are used to examine various components of performance.[55] Two decades of research, including work by the National Board of Medical Examiners, have built a strong psychometric basis for these examinations.[56–59] Increasing numbers of schools have regular performance-based testing throughout the curriculum and 59 schools report some form of comprehensive exam at the end of the third year.[2] Many schools have built elaborate clinical skills centers with multiple exam rooms, video recording, and computer monitoring capabilities, plus reception and conference rooms.

### Clinical Examination Exercise

The American Board of Internal Medicine has promoted the use of direct observation of actual clinical encounters to evaluate residents' clinical skills. In the Clinical Examination Exercises, a faculty member observes a complete work-up, including an assessment and plan, using a checklist of behaviorally anchored statements to give feedback to the resident. More recently, a mini-Clinical Examination Exercise has been developed based upon observations of more-focused outpatient encounters.[60] This form of assessment takes between 20 and 30 minutes per case. The psychometric properties of the exam are similar to an Objective Structured Clinical Examination, with 8 to12 cases required to obtain a valid sample of a resident's competence.

### Simulators

Simulations other than those offered by standardized patients are increasingly being used to assess components of clinical performance. The more high-fidelity simulations include the full-body computer-controlled anesthesia simulator designed to test real-time decision making, and Harvey, the cardiology simulator designed to test interpretation of heart sounds.[61] There are also computer-based case simulations such as Primum, developed as part of the United States Medical Licensing Examination (Step 3) to evaluate skills in managing a patient over time. Computer models of physiologic function and anatomic relationships offer opportunities to test for conceptual understanding.[62–64] Finally, virtual reality programs are emerging that can be used to test surgical skills and 3-dimensional sense.[65]

### Comprehensive Assessment and Individualized Learning Plans

At the University of Rochester, all second-year medical students complete a 2-week comprehensive assessment designed to provide extensive feedback on how well they can apply the knowledge, skills, and attitudes that they have learned to the solution of clinically relevant problems. Components of the assessment include a series of standardized patient encounters with related knowledge testing and self-learning activities, a team exercise with the Human Patient Simulator, computer-based testing of interpretative skills, peer assessment, self-assessment, and a written self-analysis of the videotapes made of the standardized patient encounters.[66,67]

## DISCUSSION

Almost every medical school has some form of curriculum renewal or educational innovation in progress. Not since the turn of the prior century has such change been so prevalent. Some of these innovations are centrally led, whereas others involve the work of one creative faculty member. This phenomenon is all the more surprising given the decreasing financial support available for medical education. It would be reasonable to expect that with the right financial incentives, educational initiatives would blossom. However, such financial resources have not fueled this revolution—in fact, quite the opposite.

Perhaps the most logical explanation for this outburst of creativity and innovation comes from the old proverb: adversity is the mother of invention. Or, as Lee Shulman wrote, "If philosophy begins in wonder, pedagogy begins in frustration."[68] Perhaps the reason for all of this reform is that medical education has become too difficult, resources are too limited, and everyone is asking, "Isn't there a better way to do this?" The innovation and change curve would support this argument. Organizations rarely change when they are succeeding and resources are expanding. Radical organizational change normally occurs when problems become too painful to ignore. Only then is there adequate political will to tackle major problems.

Another argument could be that all of the innovations described in this article are merely inadequate adaptations to overwhelming environmental forces. Thus, it is the environment and not medical education that needs to be changed. This is what the Commonwealth Fund report, *Training Tommorow's Doctors,* recommends.[6] Although we agree with the importance of public policy efforts, our focus is upon what faculty members can do to improve medical education in their schools.

Another perspective suggests that medical school faculty members are the driving force in change and that one innovation prompts another. Synergy emerges when multiple initiatives occur simultaneously, thus creating an institutional culture of creativity and change. For example, the idea for an Academy of Medical Educators at the University of California–San Francisco arose in the process of imagining a new curriculum that would no longer be bound by disciplinary boundaries and that would restore education as a valued mission of the school.

This flurry of curricular reform could also be the result of the enormous changes in the environment, as Ludmerer[8] suggests. Taking off from his suggestion, we have described 15 innovations in medical education clustered under

5 broad environmental forces. We recognize that the relationship between trends and innovations is not always straightforward. Some innovations arose prior to these forces but have flourished in recent years, whereas others appeared more recently in relation to the trend. We clustered a few innovations with specific environmental trends because they appeared related. We have attempted to make an argument for why an educational system that has remained largely unchanged since the Flexner Report[1,69] is now filled with curricular change throughout the continuum of medical education. We hope that readers will be as impressed with the remarkable scope of these innovations as we are and that it will stimulate further creativity in medical education.

What is the evidence that these innovations improve learning, satisfaction of students and teachers, or other worthy goals? In some instances, there is convincing evidence that these actions do improve learning and satisfaction. For example, many medical schools that had completed curriculum reform report improvements in: number of applicants to their medical school, national board scores, student ratings of courses, and better preparation for clerkship and residency programs.[3] Some of the innovations have empirical support based upon research conducted in higher education, such as the impact of small groups on learning.[26–29] We encourage our colleagues to join us in examining these teaching practices, contributing to our understanding of their utility and desirability.

## REFERENCES


1. Bloom S. Structure and ideology in medical education: an analysis of resistance to change. J Health Soc Behav. 1988;29:294–306.
2. Anderson MB. A snapshot of medical students' education at the beginning of the 21st century: reports from 130 schools. Acad Med. 2000;75(suppl 9):1–460.
3. The Association of American Medical Colleges. The Education of Medical Students: Ten Case Studies of Curriculum Change. New York, NY: Milbank Memorial Fund and the Association of American Medical Colleges; 2000.
4. Boex J, Boll A, Franzini L, et al. Measuring the costs of primary care education in the ambulatory setting. Acad Med. 2000;75: 419–25.
5. Cameron J. The indirect costs of graduate medical education. N Engl J Med. 1985;312:1233–8.
6. A Report of the Commonwealth Fund Task Force on Academic Health Centers. Training Tomorrow's Doctors: The Medical Education Mission of Academic Health Centers. New York, NY: Commonwealth Fund; 2002.
7. Ludmerer K. Time to Heal. New York, NY: Oxford University Press; 1999.
8. The Association of American Medical Colleges. Curriculum reform 2000: an analysis. In: The Education of Medical Students: Ten Stories of Curriculum Change. New York, NY: Milbank Memorial Fund and the Association of American Medical Colleges; 2000: 11–20.
9. Cooke M, Irby D. The UCSF academy of medical educators. Acad Med. 2002;77:455–6.
10. The Association of American Medical Colleges. University of California, San Francisco, School of Medicine. In: The Education of Medical Students: Ten Stories of Curriculum Change. New York, NY: Milbank Memorial Fund and the Association of American Medical Colleges; 2000:45–70.
11. Cuban L. How Scholars Trumped Teachers: Change Without Reform in University Curriculum, Teaching, and Research, 1890–1990. New York, NY: Teachers College Press; 1999.
12. Nutter DO, Bond JS, Coller BS, et al. Measuring faculty effort and contributions in medical education. Acad Med. 2000;75: 199–207.
13. Ridley GT, Skochelak SE, Farrell PM. Mission aligned management and allocation: a successfully implemented model of mission-based budgeting. Acad Med. 2002;77:124–9.
14. Watson R, Romrell L. Mission-based budgeting: removing a graveyard. Acad Med. 1999;74:627–37.
15. Proctor J. Faculty development programs gain ground: medical schools invest in their most valuable resource. AAMC Reporter. 2001;10:8–9.
16. Bland C, Seaquist E, Pacala J, Center B, Finstad D. One school's strategy to assess and improve the vitality of its faculty. Acad Med. 2002;77:368–76.
17. Griffith C. Evidence-based educational practice: the case for faculty development in teaching. Am J Med. 2000;109:749–52.
18. Steinert Y. Faculty development in the new millennium: key challenges and future directions. Med Teach. 2000;22:44–50.
19. Wilkerson L, Irby DM. Strategies for improving teaching practices: a comprehensive approach to faculty development. Acad Med. 1998;73:387–96.
20. Skeff K, Stratos G, Mygdal W, et al. Faculty development: a resource for clinical teachers. J Gen Intern Med. 1997;12(suppl): 56–63.
21. Skeff K, Stratos G, Mygdal W, et al. Clinical teaching improvement: past and future for faculty development. Fam Med. 1997; 29:252–7.
22. Tosteson D, Goldman H. Lessons for the future. In: Tosteson D, Adelstein S, Carver S. eds.New Pathways to Medical Education: Learning to Learn at Harvard Medical School. Cambridge, Mass: Harvard University Press; 1994:174.
23. The Medical School Objectives Writing Group. Learning objectives for medical student education. Guidelines for medical schools. Medical School Objectives Project Report I. Acad Med. 1999;74:13–8.
24. Jones R, Higgs R, deAngelis C, Prideaux D. Changing face of medical curricula. Lancet. 2001;357:699–703.
25. The Association of American Medical Colleges. University of Connecticut School of Medicine. In: The Education of Medical Students: Ten Stories of Curriculum Change. New York, NY: Milbank Memorial Fund and the Association of American Medical Colleges; 2000:91–114.
26. Bransford J, Brown A, Cocking R. How People Learn: Brain, Mind, Experience, and School. Washington, DC: National Academy Press; 1999.
27. Shuell T. Teaching and learning in a classroom context. In: Berliner D, Calfee R. eds. Handbook of Educational Psychology. New York, NY: Simon and Schuster Macmillan; 1996:726–64.
28. Brown A, Campione J. Psychological theory and the design of innovative learning environments: on procedures, principles and systems. In: Schuable L, Glaser R. eds. Innovations in Learning: New Environments for Education. Mahwah, NJ: Erlbaum; 1996: 289–325.
29. Springer L, Stanne M, Donovan S. Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: a meta-analysis. Review Educ Res. 1999;69:21–51.
30. Peters A, Greenberger-Rosovsky R, Crowder C, Block S, Moore G. Long-term outcomes of the New Pathway Program at Harvard Medical School: a randomized controlled trial. Acad Med. 2000;75: 470–9.
31. Boud D, Feletti G. The Challenge of Problem-Based Learning. 2nd ed. London: Kogan Page; 1997.
32. Dolmans D, Wolfhagen I, Scherpbier A, Bleuten C. Relationship of

tutors' group-dynamics skills to their performance ratings in problem-based learning. Acad Med. 2001;76:473–6.
33. Kaufman D, Mann K. Achievement of students in a conventional and problem-based learning (PBL) curriculum. Advances Health Sci Educ. 1999;4:245–60.
34. Ozuah P, Curtis J, Stein R. Impact of problem-based learning on residents' self-directed learning. Arch Pediatr Adoles Med. 2001; 155:669–72.
35. Issenberg S, McGahie W, Hart I, et al. Simulation technology for health care professional skills training and assessment. JAMA. 1999;282:861–6.
36. Issenberg S, Gordon M, Gordon D, Safford R, Hart I. Simulation and new learning technologies. Med Teach. 2001;23:16–23.
37. Satava R. Accomplishments and challenges of surgical simulation: dawning of the next-generation surgical education. Surg Endosc. 2001;15:232–41.
38. Jonassen D. Scaffolding diagnostic reasoning in case-based learning environments. J Comput Higher Educ. 1996;8:48–68.
39. Bower D, Bertling C. Using Palm Pilots as a teaching tool during a primary care clerkship. Acad Med. 2000;75:541–2.
40. The Association of American Medical Colleges. Tufts University School of Medicine. In: The Education of Medical Students: Ten Stories of Curriculum Change. New York, NY: Milbank Memorial Fund and the Association of American Medical Colleges; 2000:173–92.
41. Collins F. Shattuck Lecture—medical and societal consequences of the Human Genome Project. N Engl J Med. 1999;341:28–37.
42. U.S. Department of Health and Human Services. Healthy People 2010: Understanding and Improving Health. Washington, DC: U.S. Department of Health and Human Services; 2000.
43. Education Committee Writing Group of the American Geriatrics Society. Core competencies for the care of older patients. Acad Med. 2000;75:252–5.
44. The Association of American Medical Colleges. Responsive curriculum reform: continuing challenges. In: The Education of Medical Students: Ten Stories of Curriculum Change. New York, NY: Milbank Memorial Fund and the Association of American Medical Colleges; 2000:1–10.
45. National Coalition of Health Professions Education in Genetics. Core Competencies in Genetics Essential for All Health-care Professionals. Lutherville, Md: National Coalition of Health Professions Education in Genetics; 2000.
46. American Society of Human Genetics. Report from the ASHG Information and Education Committee: medical school core curriculum in genetics. Am J Hum Genet. 1995;56:535–7.
47. Friedman D. Of warps and woofs: the tapestry of medical education. Acad Med. 1993;68(suppl):50–55.
48. Curry R, Makoul G. The evolution of courses in professional skills and perspectives for medical students. Acad Med. 1998;73:10–3.
49. Magzoub ME, Schmidt HG. A taxonomy of community-based medical education. Acad Med. 2000;75:699–707.
50. Mennin SP, Kaufman A, Urbina C, McGrew M. Community-based medical education: toward the health of the public. Med Educ. 2000;34:503–4.
51. Brennan T, Leape L, Laird N, et al. Incidence of adverse events and negligence in hospitalized patients. N Engl J Med. 1991;324: 370–6.
52. Making Health Care Safer. A Critical Analysis of Patient Safety Practices. Washington, DC: Agency for Healthcare Research and Quality; 2001.
53. Institute of Medicine. To Err is Human: Building a Safer Health System. Washington, DC: National Academy Press; 2000.
54. Halpern R, Lee M, Boulter P, Phillips R. A synthesis of nine major reports on physicians' competencies for the emerging practice environment. Acad Med. 2001;76:606–15.
55. Harden R, Gleeson F. Assessment of clinical competence using an Objective Structured Clinical Examination (OSCE). Med Educ. 1979;13:41–54.
56. Reznick R, Rajarantanam K. Performance-based assessment. In: Distelhorst L, Dunnington J, Folse D, eds. Teaching and Learning in Medical and Surgical Education: Lessons Learned from the 21st Century. Mahwah, NJ: Lawrence Erlbaum; 2000:237–43.
57. Colliver J, Swartz M. Reliability and validity issues in standardized patient assessment. In: Distelhorst L, Dunnington G, Folse J, eds. Teaching and Learning in Medical and Surgical Education: Lessons Learned for the 21st Century. Mahwah, NJ: Lawrence Erlbaum Associates; 2000:229–35.
58. Anderson M, Stillman P, Wang Y. Growing use of standardized patients in teaching and evaluation in medical education. Teach Learn Med. 1994;6:15–22.
59. Barrows H. An overview of the uses of standardized patients for teaching and evaluating clinical skills. Acad Med. 1993;68:443–51.
60. Norcini J, Blank U, Arnold GK, Kimball HR. The Mini-CEX (Clinical Evaluation Exercise): a preliminary investigation. Ann Intern Med. 1995;123:795–9.
61. Issenberg S, Petrusa E, McGaghie W, et al. Effectiveness of a computer-based system to teach bedside cardiology. Acad Med. 1999;74(suppl):93–5.
62. Dwyer T, Fleming J, Randall J, Coleman T. Teaching physiology and the World Wide Web: electrochemistry and electrophysiology on the Internet. Am J Physiol. 1997;273():S2–S13.
63. Stevens R, Lopo A, Wang P. Artificial neural networks can distinguish novice and expert strategies during complex problem solving. JAMA. 1996;3:131–8.
64. Trelease R, Nieder G, Dorup J, Hansen M. Going virtual with QuickTime VR: new methods and standardized tools for interactive dynamic visualization of anatomical structures. Anat Rec. 2000;261:64–77.
65. Hoffman H. Teaching and learning with virtual reality. Stud Health Tech Inform. 2000;79:285–91.
66. Epstein R. Second-Year Comprehensive Assessment: Manual of the Curricular Affairs Office. Rochester, NY: University of Rochester School of Medicine and Dentistry; 2002.
67. Epstein R, Hundert E. Defining and assessing professional competence. JAMA. 2002;287:226–35.
68. Shulman L. Toward a pedagogy of cases. In: Shulman J, ed. Case Methods in Teacher Education. New York, NY: Teachers College Press; 1992:1–30.
69. Cuban L. Change without reform: the case of Stanford University School of Medicine, 1908–1990. Am Educ Rec J. 1997;34:83–122.