

# Can Scientific Research Enhance the Art of Teaching? \*†

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Raphael: *The School of Athens - Both Art and Science* (see, e.g., <[http://en.wikipedia.org/wiki/The\\_School\\_of\\_Athens](http://en.wikipedia.org/wiki/The_School_of_Athens)>

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\*Based on Hake, R.R. 2007. "Should We Measure Change? Yes!" online as a 2.5 MB pdf at <<http://tinyurl.com/38perp>> or ref. 43 at <<http://www.physics.indiana.edu/~hake>>. To appear as a chapter in *Evaluation of Teaching and Student Learning in Higher Education*, a Monograph of the American Evaluation Association <<http://www.eval.org/>>.

†The reference is Hake, R.R. 2007. "Can Scientific Research Enhance the Art of Teaching?" Invited talk, AAPT Greensboro meeting, 31 July, online at <<http://www.physics.indiana.edu/~hake/Sci&Art3.pdf>> (1.2 MB), or as ref. 50 at <<http://www.physics.indiana.edu/~hake/>>.

◇ All URL's are hot-linked; accessed on 13 August 2007. Tiny URL's courtesy <<http://tinyurl.com/create.php>>.

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## **OUTLINE\***

**I. Proponents of the “Art of Teaching” – 1899 to 1983**

**II. Teaching is *Both* an Art and a Science**

**III. Can Science Improve Teaching Effectiveness?**

**IV. Development of Multiple-Choice Tests of Higher-Level Learning**

**V. University Leaders Bemoan the Inertia of Higher Education: Why Is It So Slow To Recognize the Value of Interactive Engagement Methods in Promoting Higher-Level Learning?**

**VI. Why Should We Be Concerned with Student Learning?**

**VII. Epilogue**

\*Due to the time constraint, among topics discussed in Hake (2007a) that will *not* be covered in this talk are: (a) normalized gain and ceiling effects, (b) the probable neuronal basis for the superiority of interactive-engagement pedagogy, (c) education’s lack of a community map; (d) higher education’s failure to assist in the substantive improvement of the public schools.

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Hake, R.R. 2007a. “Should We Measure Change? Yes!” online at <<http://tinyurl.com/38perp>> or ref. 43 at <<http://www.physics.indiana.edu/~hake>>. To appear as a chapter in *Evaluation of Teaching and Student Learning in Higher Education*, a Monograph of the American Evaluation Association <<http://www.eval.org/>>.

## I. Proponents of the “Art of Teaching” – 1899 to 1983

*“Psychology is a science, and teaching is a art; and sciences never generate arts directly out of themselves. An intermediary inventive mind must make the application, by using its originality.”*

William James (1899)

*“Teaching, I say, is an art, and not a science. . . in no sense can teaching be said to be a science.”*

Floyd Richtmyer (1933) [referenced in Hestenes (1979)]

*“This book is called ‘The Art of Teaching’ because I believe that teaching is an art, not a science.”*

Gilbert Highet (1950) [referenced in Hestenes (1979)]

*“After more than two-score years [Richtmyer’s statement] has not been proven wrong.”*

Ralph Goodwin (1978) [referenced in Hestenes (1979)]

*“Teachers are more like orchestra conductors than technicians. They need rules of thumb and educational imagination, not scientific prescriptions.”*

Elliot Eisner (1983)

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James, W. 1899. "Talks to Teachers On Psychology and To Students on Some of Life's Ideals." Henry Holt & Co, esp. Chapter 1 "Psychology and the Teaching Art," online at <<http://www.des.emory.edu/mfp/tt1.html>>.

Richtmyer, F.K. 1933. “Physics is Physics,” *Am. J. Phys.* **1** (1): 2-5; online to subscribers at <<http://tinyurl.com/364ns6>>.

Highet, G. 1950. *The Art of Teaching*. Alfred A. Knopf. Now available in a 1989 Vintage edition; Amazon.com information at <<http://tinyurl.com/2eom35>>.

Goodwin, R.A. 1978. “Chalk and Chalk,” *Phys. Teach.* **16**(6):, 367-372 (1978); online to subscribers at <<http://tinyurl.com/2zu8wc>>.

Hestenes, D. 1979. “Wherefore a science of teaching?” *The Physics Teacher* **17**(4): 235-242; online at <[http://modeling.asu.edu/R&E/Wherefore\\_SciOfTeaching.PDF](http://modeling.asu.edu/R&E/Wherefore_SciOfTeaching.PDF)> (56 kB).

Eisner, E. 1983. *The Art and Craft of Teaching*. *Educational Leadership* **40**(4): 4-13; online at <[http://www.ascd.org/ASCD/pdf/journals/ed\\_lead/el\\_198301\\_eisner.pdf](http://www.ascd.org/ASCD/pdf/journals/ed_lead/el_198301_eisner.pdf)> (2 MB).

## II. Teaching is *Both* an Art and a Science

*“Let us agree at the outset that good teaching is an art, fully deserving our respect and admiration. It does not follow, however, as Goodwin seems to think, that there cannot also be a science of teaching. . . . . Medical practice is widely acknowledged to be an art,*



*but who doubts the possibility of medical science?*



*Is teaching so different because it ministers to the mind?”*

David Hestenes (1979)

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Hestenes, D. 1979. “Wherefore a science of teaching?” *The Physics Teacher* **17**(4): 235-242; online at <[http://modeling.asu.edu/R&E/Wherefore\\_SciOfTeaching.PDF](http://modeling.asu.edu/R&E/Wherefore_SciOfTeaching.PDF)> (56 kB).

### III. Can Science Improve Teaching Effectiveness?

*“I did what everyone else did: lectures. And the feedback was positive. . . . when I gave them . . . [the Halloun-Hestenes (1985a,b) (HH) concept-based exam]. . . about half had no clue as to what Newtonian mechanics were about.”*

Eric Mazur, quoted in Dreifus (2007)



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Dreifus, C. 2007. "A Conversation With Eric Mazur: Using the 'Beauties of Physics' to Conquer Science Illiteracy," *New York Times*, 17 July, online at <<http://tinyurl.com/ysab9b>>. See also Hake (2007b).

Hake, R.R. 2007b. "A Conversation With Eric Mazur," post of 23 Jul 2007 17:10:06-0700 to AERA-L; online at <<http://tinyurl.com/2zo3pz>>.

Halloun, I. & D. Hestenes. 1985a. "The initial knowledge state of college physics students." *Am. J. Phys.* **53**: 1043-1055; online at <<http://modeling.asu.edu/R&E/Research.html>>. Contains the "Mechanics Diagnostic" test, precursor to the "Force Concept Inventory" [Hestenes et al. (1992)].

Halloun, I. & D. Hestenes. 1985b. "Common sense concepts about motion." *Am. J. Phys.* **53**: 1056-1065; online at <<http://modeling.asu.edu/R&E/Research.html>>.

Hestenes, D., M. Wells, & G. Swackhamer. 1992. "Force Concept Inventory," *Phys. Teach.* **30**: 141-158; online (except for the test itself) at <<http://modeling.asu.edu/R&E/Research.html>>. The 1995 revision by Halloun, Hake, Mosca, & Hestenes is online (password protected) at the same URL, and is available in English, Spanish, German, Malaysian, Chinese, Finnish, French, Turkish, Swedish, and Russian.

Mazur then shifted to "Peer Instruction" [Mazur (1997), Crouch & Mazur (2001), Rosenberg et al. (2006), Crouch et al. (2007)] an interactive-engagement type of pedagogy that, on the first try, resulted in a factor two increase in pre-to-post test normalized gains on the Halloun-Hestenes test.

I shall forego enumerating the research that is consistent with Mazur's experience and with a nearly two-standard-deviation superiority [Hake (1998a,b; 2002a,b)] in normalized conceptual gains of interactive engagement pedagogy over traditional direct instruction – *except* (see next page):

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Crouch, C.H. & E. Mazur. 2001. "Peer Instruction: Ten years of experience and results," *Am. J. Phys.* **69**: 970-977; online at <<http://tinyurl.com/sbys4>>.

Crouch, C.H., J. Watkins, A. Fagen, & E. Mazur. 2007. "Peer Instruction: Engaging students one-on-one, all at once," in *Research-Based Reform in University Physics*, E.F. Redish, ed.; online at <<http://mazur-www.harvard.edu/publications.php?function=search&topic=8>>.

Hake, R.R. 1998a. "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**(1): 64-74; online at <<http://www.physics.indiana.edu/~sdi/ajpv3i.pdf>> (84 kB).

Hake, R.R. 1998b. "Interactive-engagement methods in introductory mechanics courses," online at <<http://www.physics.indiana.edu/~sdi/IEM-2b.pdf>> (108 kB) - a crucial companion paper to Hake (1998a).

Hake, R.R. 2002a. "Lessons from the Physics Education Reform Effort," *Ecology and Society* **2**: 28; online at <<http://www.ecologyandsociety.org/vol5/iss2/art28/>>.

Hake, R.R. 2002b. "Assessment of Physics Teaching Methods," *Proceedings of the UNESCO ASPEN Workshop on Active Learning in Physics*, Univ. of Peradeniya, Sri Lanka, 2-4 Dec.; online at <<http://www.physics.indiana.edu/~hake/Hake-SriLanka-Assessb.pdf>> (84 kB).

Mazur, E. 1997. *Peer instruction: A user's manual*. Prentice-Hall: description online at <[http://mazur-www.harvard.edu/education/pi\\_manual.php](http://mazur-www.harvard.edu/education/pi_manual.php)>.

Rosenberg, J., Lorenzo, M., & Mazur, E. 2006. "Peer instruction: Making science engaging," in J.J. Mintzes and W.H. Leonard, eds., *Handbook of College Science Teaching* (pp. 77-85). NSTA Press, online at <<http://mazur-www.harvard.edu/publications.php?function=search&topic=8>>.

for giving these references ; - ) from “Design-Based Research in Physics Education Research: A Review” [Hake (2007c)]:

Redish, Saul, & Steinberg, 1997; Saul, 1998; Adams & Noonan (1998); Heller (1999); Redish & Steinberg (1999); Redish (1999); Beichner et al. (1999); Cummings, Marx, Thornton, & Kuhl (1999); Novak, Patterson, Gavrin, & Christian (1999); Bernhard (2000); Crouch & Mazur (2001); Johnson (2001); Meltzer (2002a, 2002b); Meltzer & Manivannan (2002); Savinainen & Scott (2002a, 2002b); Steinberg & Donnelly (2002); Fagan, Crouch, & Mazur (2002); Van Domelen & Van Heuvelen (2002), Belcher (2003); Dori & Belcher (2004); Hoellwarth, Moelter, & Knight (2005); Lorenzo, Crouch, & Mazur (2006); & Rosenberg, Lorenzo, & Mazur (2006).

**BUT WAIT!** Considering the canonical arguments regarding the invalidity of pre/post testing evidence, should not all the results cited above be viewed with grave suspicion? As discussed in Hake (2007a), the anti pre/post testing arguments by psychometric authorities such as Cronbach and Furby (1970) that gain scores are unreliable have been called into question by, for example [see Hake (2007a) for the references]: Rogosa, Brandt, & Zimowski (1982), Zimmerman & Williams (1982), Rogosa & Willett (1983, 1985), Rogosa (1995), Wittmann (1997), Zimmerman (1997), & Zumbo (1999). All this more recent work should serve as an antidote for the emotional, pre/post paranoia [Hake (2006)] that grips many educational researchers.

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Cronbach, L. & L. Furby. 1970. “How we should measure ‘change’- or should we?” *Psychological Bulletin* **74**: 68-80.

Hake, R.R. 2006. “Possible Palliatives for the Paralyzing Pre/Post Paranoia that Plagues Some PEP’s,” *Journal of MultiDisciplinary Evaluation*, Number 6, November, online at [http://evaluation.wmich.edu/jmde/JMDE\\_Num006.html](http://evaluation.wmich.edu/jmde/JMDE_Num006.html).

Hake, R.R. 2007a. “Should We Measure Change? Yes!” online at <http://tinyurl.com/38perp> or ref. 43 at <http://www.physics.indiana.edu/~hake>. To appear as a chapter in *Evaluation of Teaching and Student Learning in Higher Education*, a Monograph of the American Evaluation Association <http://www.eval.org/>.

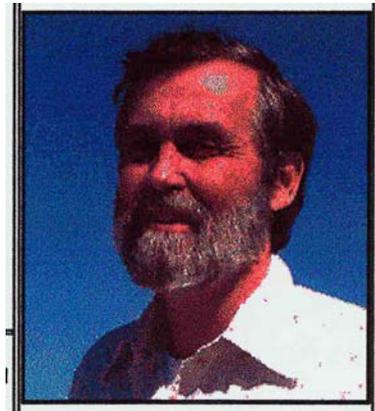
Hake, R.R. 2007c. “Design-Based Research in Physics Education Research: A Review” in A.E. Kelly, R.A. Lesh, & J.Y. Baek (in press), *Handbook of Design Research Methods in Mathematics, Science, and Technology Education*. Lawrence Erlbaum; online at <http://www.physics.indiana.edu/~hake/DBR-Physics3.pdf> (1.1 MB).

#### IV. Development of Multiple-Choice Tests of Higher-Level Learning

Pre/post testing is only as good as the tests employed. In some fields, *disciplinary experts* have engaged, or are engaging, in the arduous quantitative and qualitative research required to develop valid and consistently reliable tests that probe for understanding of the basic concepts. A model for such effort is the pioneering but under-appreciated work of Halloun & Hestenes(1985a,b) in developing the *Mechanics Diagnostic Test*, precursor to the widely used *Force Concept Inventory* [Hestenes et al. (1992)].



Ibrahim Halloun



David Hestenes

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Halloun, I. & D. Hestenes. 1985a. "The initial knowledge state of college physics students." *Am. J. Phys.* **53**: 1043-1055; online at <http://modeling.asu.edu/R&E/Research.html>. Contains the "Mechanics Diagnostic" test, precursor to the "Force Concept Inventory" [Hestenes et al. (1992)].

Halloun, I. & D. Hestenes. 1985b. "Common sense concepts about motion." *Am. J. Phys.* **53**: 1056-1065; online at <http://modeling.asu.edu/R&E/Research.html>.

Hestenes, D., M. Wells, & G. Swackhamer. 1992. "Force Concept Inventory," *Phys. Teach.* **30**: 141-158; online (except for the test itself) at <http://modeling.asu.edu/R&E/Research.html>. The 1995 revision by Halloun, Hake, Mosca, & Hestenes is online (password protected) at the same URL, and is available in English, Spanish, German, Malaysian, Chinese, Finnish, French, Turkish, Swedish, and Russian.

*BUT WAIT!* Can multiple choice tests gauge higher level cognitive outcomes such as the conceptual understanding of Newtonian mechanics? Wilson & Bertenthal (2005) think so, writing (p. 94):

*“ . . . . .although many people recognize that multiple-choice items are an efficient and effective way of determining how well students have acquired basic content knowledge, many do not recognize that they can also be used to measure complex cognitive processes. For example, the Force Concept Inventory . . . [Hestenes, Wells, & Swackhamer, 1992] . . .is an assessment that uses multiple-choice items to tap into higher-level cognitive processes.”*

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Hestenes, D., M. Wells, & G. Swackhamer. 1992. “Force Concept Inventory,” *Phys. Teach.* **30**: 141-158; online (except for the test itself) at <<http://modeling.asu.edu/R&E/Research.html>>. The 1995 revision by Halloun, Hake, Mosca, & Hestenes is online (password protected) at the same URL, and is available in English, Spanish, German, Malaysian, Chinese, Finnish, French, Turkish, Swedish, and Russian.

Wilson, M.R. & M.W. Bertenthal, eds. 2005. *Systems for State Science Assessment*, Nat. Acad. Press; online at <[http://www.nap.edu/catalog.php?record\\_id=11312](http://www.nap.edu/catalog.php?record_id=11312)>.

## V. University Leaders Bemoan the Inertia of Higher Education: Why Is It So Slow To Recognize the Value of Interactive Engagement Methods in Promoting Higher-Level Learning?



Derek Bok (2005a), former (and now interim), president of Harvard University (shown here addressing the Harvard's *Bok Center for Teaching and Learning* <<http://bokcenter.harvard.edu/icb/icb.do>> at its Fall 2006 Teaching Conference) wrote:

*“ . . . studies indicate that problem-based discussion, group study, and other forms of active learning produce greater gains in critical thinking than lectures, yet the lecture format is still the standard in most college classes, especially in large universities.”*

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Bok, D. 2005a. “Are colleges failing? Higher ed needs new lesson plans,” Boston Globe, 18 December, copied into the APPENDIX of Hake (2005). See also Bok (2005b).

Bok, D. 2005b. *Our Underachieving Colleges: A Candid Look at How Much Students Learn and Why They Should Be Learning More*. Princeton University Press - information including the preface and Chapter 1 is online at <<http://press.princeton.edu/titles/8125.html>>.

Hake, R.R. 2005. “Are colleges failing?” AERA-L post of 19 Dec 2005 17:54:37-0800; online at <<http://tinyurl.com/2rdc88>>.



James Duderstadt (2000), President Emeritus and University Professor of Science and Engineering at the University of Michigan, in *A University for the 21st Century*, made much the same point, writing:

*“Few faculty members have any awareness of the expanding knowledge about learning from psychology and cognitive science. Almost no one in the academy has mastered or used this knowledge base. One of my colleagues observed that if doctors used science the way college teachers do, they would still be trying to heal with leeches.”*

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Duderstadt, J.J. 2000. *A University for the 21st Century*. Univ. of Michigan Press; for a description see <<http://tinyurl.com/9lhpl>>. See also Duderstadt (2001, 2007); & Duderstadt et al. (2005).

Duderstadt, J. J. 2001. “Science policy for the next 50 years: from guns to pills to brains,” in *Proceedings of the AAAS Annual Meeting*, San Francisco, February; online at <[http://milproj.umm.umich.edu/publications/aaas\\_text\\_2/aaas\\_text\\_2.pdf](http://milproj.umm.umich.edu/publications/aaas_text_2/aaas_text_2.pdf)> (356 kB).

Duderstadt, J., W.A. Wulf, & R. Zemsky. 2005. “Envisioning a Transformed University,” *Issues in Science and Technology* **22**(1): 35-41. National Academy Press; online at <<http://www.issues.org/22.1/duderstadt.html>>.

Duderstadt, J. J. 2007. “The Future of the University: A Perspective from the Oort Cloud,” online at <<http://tinyurl.com/yu8pt9>>. For “Oort Cloud” see <[http://en.wikipedia.org/wiki/Oort\\_cloud](http://en.wikipedia.org/wiki/Oort_cloud)>.



*Richard M. Cyert*  
*19th President of TIMS*

Richard Cyert, former president of Carnegie Mellon University [and 19th President of “The Institute of Management Sciences” (TIMS)], wrote in Tuma & Reif (1980):

*“The academic area is one of the most difficult areas to change in our society. We continue to use the same methods of instruction, particularly lectures, that have been used for hundreds of years. Little scientific research is done to test new approaches, and little systematic attention is given to the development of new methods. Universities that study many aspects of the world ignore the educational function in which they are engaging and from which a large part of their revenues are earned.”*

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Tuma, D.T. & F. Reif, eds. 1980. *Problem Solving and Education: Issues in Teaching and Research*, Lawrence Erlbaum.



Fred Reif (1974), a physics-education-research pioneer, in commentary as relevant today as it was 33 years ago, wrote:

*“The university does not systematically encourage faculty members to turn their talents to educational endeavors; in fact such endeavors are usually regarded as being of dubious legitimacy compared to more prestigious activities. . . . educational innovations are few in number and often marginal in their impact. Nor is this situation surprising, since the university, unlike any progressive industry, is not in the habit of improving its own performance by systematic investment in innovative research and development.”*

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Reif, F. 1974. “Educational Challenges for the University,” *Science* **184**: 537-542.

## VI. Why Should We Be Concerned with Student Learning?

Although international competitiveness is often cited by educational leaders, politicians, and business executives –see e.g., *Rising Above the Gathering Storm* [COSEPUP (2006)] - more crucial in my view is the need to overcome the monumental problems now *threatening life on planet Earth*. The sagacious James Duderstadt (2000, p. 20) wrote:

“SPACESHIP EARTH: There is mounting evidence that the growing population and invasive activities of humankind are now altering the fragile balance of our planet. The concerns are both multiplying in number and intensifying in severity: the destruction of forests, wetlands and other natural habitats by human activities leading to extinction of millions of biological species and the loss of biodiversity; the buildup of greenhouse gases such a carbon dioxide and their possible impact on global climates; the pollution of our air, water, and land.

With the world population now at 6 billion, we are already consuming 40% of the world's photosynthetic energy production. Current estimates place a stable world population at about 8 to 10 billion by the late twenty-first century, assuming fertility rates continue to drop over the next several decades. Yet even at this reduced rate of population growth, we could eventually consume all of the planet's resources, unless we take action. Because of this overload of the world's resources, even today, over 1.2 billion of the world's population live below the subsistence level, and 500 million below the minimum caloric intake level necessary for life.

It could well be that coming to grips with the impact of our species on our planet, learning to live in a sustainable fashion on spaceship earth, will become the greatest challenge of our generation. This will be particularly difficult for a society that has difficulty looking more than a generation ahead, encumbered by a political process that generally functions on an election-by-election basis, as the current debate over global change makes all too apparent. **UNIVERSITIES MUST TAKE THE LEAD IN DEVELOPING KNOWLEDGE AND EDUCATING THE WORLD'S CITIZENS TO ALLOW US TO LIVE UPON OUR PLANET WHILE PROTECTING IT.” [My CAPS.]**

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COSEPUP. 2005. COmmittee on Science, Engineering, and PUBlic Policy, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future*," National Academies Press; online at <<http://books.nap.edu/catalog/11463.html>>.

Duderstadt, J.J. 2000. *A University for the 21st Century*. Univ. of Michigan Press; for a description see <<http://tinyurl.com/9lhpl>>.

In Hake (2000), I listed 14 life-threatening problems\* and cited the imperative to (a) educate more effective science majors and science-trained professionals, and (b) raise the appallingly low level of science literacy among the general population by, among other things, properly educating prospective K-12 teachers.

\* **A. Political-Scientific** (a few of many examples)

1. Overpopulation (doubles about every 35 years)
2. Threat of weapons of mass destruction
3. Human welfare (starvation, homelessness, unemployment, drugs, epidemics, AIDS, etc.)
4. Environment (pollution of air, water, land, food; global warming; ozone depletion; deforestation; loss of biodiversity)
5. Long-term energy crisis: man-made waste heat approaches Sun's input heat to Earth; depletion of fossil fuels
7. Third world crises
8. Superstition
9. Terrorism

**B. Economic-Scientific** (a few of many examples)

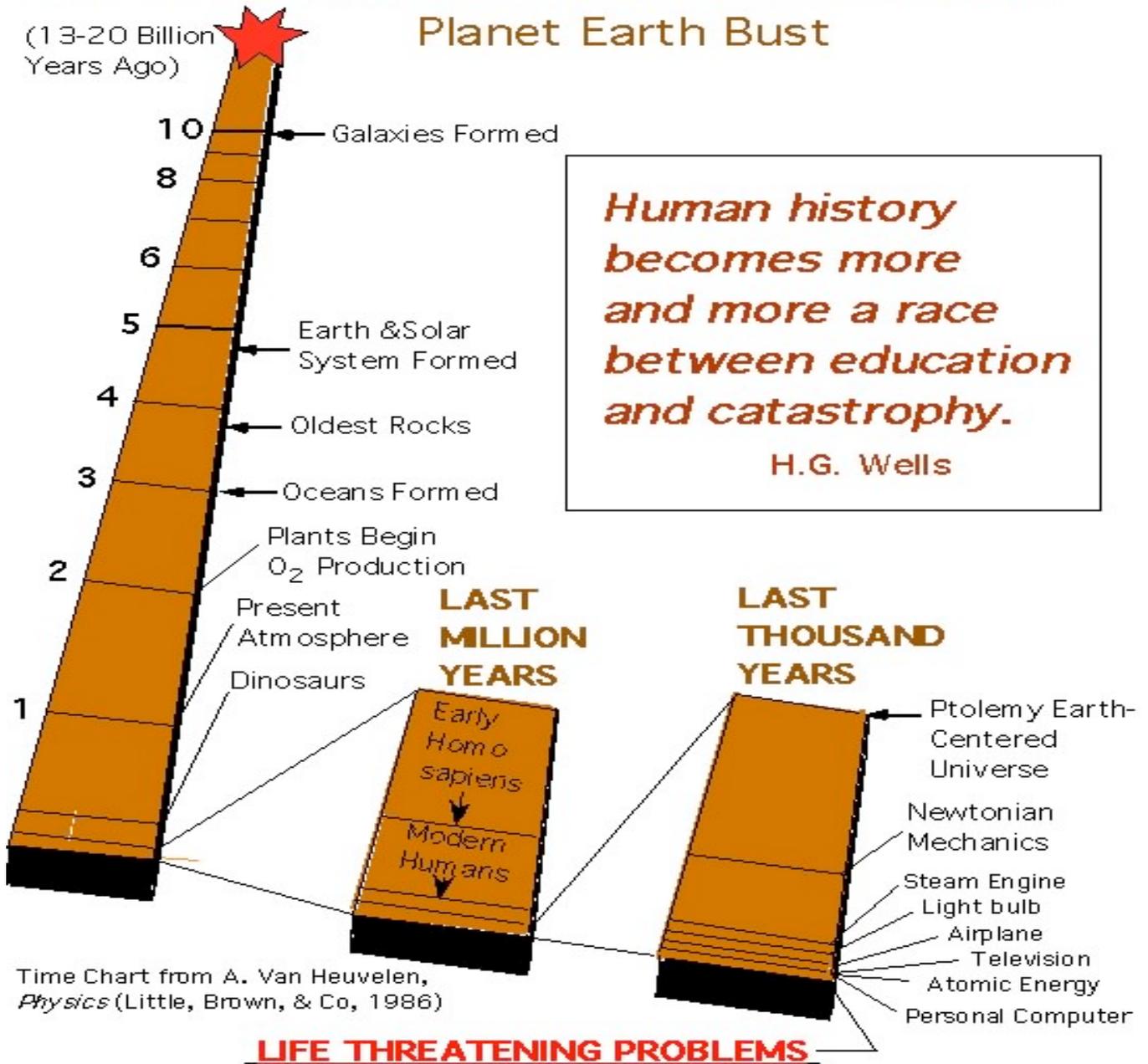
10. Natural resource waste (fossil fuels, forests, grasslands, rivers, ecosystems)
11. Widening gap between the rich and the poor
12. Lowering of living standards in many countries
13. Human resource waste (minorities, lower castes, women)
14. Unemployment

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Hake, R.R. 2000. "The General Population's Ignorance of Science Related Societal Issues: A Challenge for the University," *AAPT Announcer* **30**(2): 105; online at <<http://www.physics.indiana.edu/~hake/GuelphSocietyG.pdf>> (2.1 MB). Based on an earlier libretto with the leitmotiv: "**The road to U.S. science literacy begins with effective university science courses for pre-college teachers.**" The opera dramatizes the fact that the failure of universities throughout the universe to properly educate pre-college teachers is responsible for our failure to observe any signs of extraterrestrial (and even terrestrial) intelligence.

## VII. Epilogue [from Hake (2000)]

### From the **BIG BANG** to the Possible Life On Planet Earth Bust



Hake, R.R. 2000. "The General Population's Ignorance of Science Related Societal Issues: A Challenge for the University," *AAPT Announcer* **30**(2): 105; online at <http://www.physics.indiana.edu/~hake/GuelphSocietyG.pdf> (2.1 MB).