Making Science a Core Liberal Art for the 21st Century

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Abstract: Courses in physical science are core to both secondary and post-secondary education. Yet it seems that science is not generally viewed as a core liberal art. While other approaches may help science move closer to that goal, this paper focuses on epistemic opportunities. Given the ongoing success of the sciences in building cumulative knowledge about the natures and causes of things, it is argued that the sciences may have operationally embodied certain epistemic principles for forming cumulative knowledge that may be helpful in dealing with the human condition. Despite the great risks involved in this area, any advances in identifying and justifying these epistemic principles would provide a conceptual dividend that would repay the investment many times over. Supporting such efforts in the philosophy of science should be an integral part of any effort to make science a core liberal art in the 21st century.

1. Background

Is science a core liberal art? This question is the subject of the Fifth Annual Conversation on the Liberal Arts.[1] In this paper, 'science' is used as a synonym for the physical sciences such that the social sciences are not included. As Steen (1991) noted, 'science' is singular yet the components are many. Thus the question as stated is too broad to be answered. Henceforth, 'science' will be used to stand for those elements that are common to all physical sciences. From a broader perspective, this issue must involve answering "What does it mean to be liberally educated in the 21st century?"[2] This paper reviews some relevant material on both questions.

2. Science As a Core Area of Study

For over 100 years, there has been a broad consensus among science educators that science is a necessary component – a core area of study – for educated adults. This long-standing consensus is seen in the 1893 report by the Committee of Ten that recommended that science courses be at least 25% of the school curriculum (Appendix A), in the developments in the 20th century (Appendix B) and in the recent activities of the American Association for the Advancement of Science (AAAS) in focusing on science literacy (Appendix C). It might seem that having succeeded in embedding science as a core area of study in school education for over 100 years would provide a strong argument for concluding that science is indeed a core liberal art.

But the idea of a core liberal art applies to post-secondary education so what happens during secondary education may be relevant but not necessarily conclusive. Moreover, faculty in the liberal arts – and particularly in the humanities – may have a different view of a liberal education than do science educators. To see this, consider a brief history of the nature of a liberal education.

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[1] The Fifth Annual Conversation on the Liberal Arts, "*Beyond Two Cultures: the Sciences as Liberal Arts*," will be hosted by the Institute for the Liberal Arts at Westmont College in Santa Barbara, California, February 18 and 19, 2005. That conference will address three specific questions. (1) How do the sciences contribute to the goals of a liberal arts education? (2) How can they be a part of an integrated and coherent liberal arts curriculum? (3) And how can community be fostered among faculty from very different academic cultures? See www.westmont.edu/institute/.

[2] The National Science Foundation, Directorate for Education and Human Resources/Division of Undergraduate Education (www.ehr.nsf.gov/), is calling for conversations on that question. Project Kaleidoscope (PKAL) has been asked to engage colleagues within the nation's liberal arts colleges and comprehensive universities on addressing this question. www.pkal.org/template2.cfm?c_id=1492.

3. A Liberal Education

The Association of American Colleges and Universities (AAC&U)[3] is in the forefront in reviewing the nature of a liberal education. A common theme is that of change or transformation. AACU President, Carol Schneider (2004)[4] noted that "*liberal education at the start of the twenty-first century is anything but a moribund tradition. Historically, the practice of liberal education has changed radically over the centuries, and it is in the midst of far-reaching—if largely unreported—change today*."

In 1943, Harvard President Conant[5] commissioned a report, *General Education in a Free Society*, better known as the Red Book. This report served as a bridge between an earlier classics-based education for a small elite and a distribution-based liberal education for the general population.

In 1983, the Gardner report (the Nation at Risk)[6] noted problems at that time and the need for change in higher education. In 1984, the associated report (A Nation Responds)[7] indicated changes underway. In 1992, Ponder and Holmes[8] noted the continuing call for change was creating negative side effects and stressed the need for an over-arching review of the educational paradigm. In 1997, Lanham[9] called for an updated report to the Harvard Red Book to serve as the bridge between the present and the future saying, "*now, we must teach our students how to meet the higher, and different, demands for symbolic thought imposed by an information-based society*."

In 2002, the AACU completed a major effort to identify the "expectations" of 21st century liberal education. [10,11] The Greater Expectations Report (AACU 2002) "*calls for a dramatic reorganization of undergraduate education to ensure that all college aspirants receive not just access to college, but an education of lasting value. The panel offers a new vision that will promote the kind of learning students need to meet emerging challenges in the workplace, in a diverse democracy, and in an interconnected world. The report also proposes a series of specific actions and collaborations to raise substantially the quality of student learning in college. The panel concludes that change is urgently needed. Even as college attendance is rising, the performance of too many students is faltering. Public policies have focused on getting students into college, but not on what they are expected to accomplish once there. The result is that the college experience is a revolving door for millions of students, while the college years are poorly spent by many others. Broad, meaningful reform in higher education is long overdue. The near-universal demand for higher learning in the United States creates new urgency, opportunity, and responsibility to revitalize the practice of undergraduate education.*"

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[3] www.AACU.org
[4] www.aacu-edu.org/publications/practicing_liberal_education.cfm
[5] President Conant sensed the coming revolution when he charged the committee. "The primary concern of American education today," he wrote, "is not the development of the appreciation of the 'good life' in young gentlemen born to the purple. It is the infusion of the liberal and humane tradition into our entire educational system. Our purpose is to cultivate in the largest possible number of our future citizens an appreciation of both the responsibilities and the benefits which come to them because they are Americans and are free." (*GE*, xiv-xv)
[6] www.ed.gov/pubs/NatAtRisk/index.html
[7] The Nation Responds (U.S. Department of Education, May, 1984)
[8] www.ilt.columbia.edu/publications/papers/Ponder.html
[9] www.rhetoricainc.com/harvard.html
[10] www.greaterexpectations.org/briefing_papers/GoalsForLiberalLearning.html
[11] According to the AACU, "Greater Expectations (GEx) is AAC&U's multi-year initiative to articulate the aims of a 21st century liberal education and identify comprehensive, innovative models that improve learning for all undergraduate students. GEx will help develop learner-centered campus programs in liberal education, and will link promising practices in higher education and secondary school reform."

4. Is Science a Core Discipline in the Liberal Arts?

The role of science as a core discipline is clearly appreciated and definitely supported by those disciplines that are science based. The Accreditation Board for Engineering and Technology, Inc. (ABET)[12] holds that **"**Engineering programs must demonstrate that their graduates have (a) an ability to apply knowledge of mathematics, science, and engineering, (b) an ability to design and conduct experiments, as well as to analyze and interpret data, and (c) an ability to design a system, component, or process to meet desired needs. The American Association of Colleges of Nursing (AACN)[13] holds that, "Liberal learning provides a solid foundation for the development of clinical judgment skills required for the practice of professional nursing... Liberal education should provide the professional nurse with the ability to: (a) develop and use higher—order problem-solving and critical thinking skills; (b) integrate concepts from behavioral, biological, and natural sciences in order to understand self and others; (c) interpret and use quantitative data; (d) use the scientific process and scientific data as a basis for developing, implementing, and evaluating nursing interventions…"

But the central role of science in general education is much less obvious from a liberal-arts perspective. Note that in earlier times the term 'general education' was understood to be that part of a liberal education taken by all students at a college. But the use of two distinct terms (liberal education vs. general education) foreshadowed their potential separation. Indeed we now have a newer term, core curriculum, which simply identifies those courses that all students must take. Thus if a college wanted all students to become familiar with the production of value for use, students might be required to complete a core courses in business, technology or engineering even though such courses are not currently considered part of a liberal education. Thus, even if educators agree that science is a core discipline or even a core component of general education, this is not sufficient to conclude that science is a core liberal art.

Despite the lack of clarity in what constitutes the liberal arts and despite the aforementioned changes in the delivery of course content, in pedagogy and in assessment, Schneider and Schoenberg (1998) noted that a constant goal for a liberal education is to provide "the kinds of learning students need to negotiate a rapidly transforming world."

The American Academy for Liberal Education (AALE)[14] holds that "*Liberal education aims at creating free men and women, those who have control over their lives, not only vocationally, but as citizens and as human beings able to draw on the greatest minds and works of both the past and the present. The Academy understands general undergraduate education to have three broad goals: (a) the cultivation of responsible citizens; (b) preparation for the world of work; and (c) the pursuit of knowledge for its own sake*."

The Commission on Institutions of Higher Education, New England Association of Schools and Colleges (NEASC)[15] holds that "*Graduates demonstrate competence in written and oral communication in English; the ability for scientific and quantitative reasoning, for critical analysis and logical thinking; and the capacity for continuing learning. They also demonstrate knowledge and understanding of scientific, historical, and social phenomena, and a knowledge and appreciation of the aesthetic and ethical dimensions of humankind*."

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[12] www.abet.org/downloads/2000_01_Engineering_Criteria.pdf.
[13] From The Essentials of Baccalaureate Education for Professional Nursing Practice, American Association of Colleges of Nursing, 1998, Washington, DC.
[14] From www.aale.org, Education Standards.
[15] From www.neasc.org/cihe/stancihe.htm.

In summarizing the learning goals from 16 different colleges and universities, the AACU noted that almost all referred to eleven learning goals: (1) Communication, most especially writing, (2) Critical thinking and problem solving, (3) Ethical issues/values, (4) Quantitative reasoning, (5) Cross-cultural understanding, sometimes specifically expanded to the global environment, (6) Citizenship, (7) Diverse disciplines (as contexts for learning, ways of constructing knowledge, etc.), (8) Integration (e.g., among disciplines, between theory and practice), (9) Self-knowledge/personal values, (10) Team work and collaborative learning and (11) Life-long learning.

In summarizing the results from the aforementioned accrediting organizations and from the aforementioned colleges and universities, the AACU noted[16] that, "a broad consensus on learning goals is implicit in contemporary campus efforts: (1) Acquiring intellectual skills or capacities: writing, quantitative reasoning, oral expression, technological literacy, second language, moral reasoning, and negotiating difference. (2) Understanding and using multiple modes of inquiry and approaches to knowledge in humanities, arts, sciences and social sciences. (3) Developing societal, civic, and global knowledge, (4) Gaining self-knowledge and grounded values and (5) Achieving concentration and integration of learning: inquiry-based learning in the major, and integrative learning within majors, across fields, between general studies and majors, in and out of school."

In summary, the AALE statement did not mention science. The NEASC statement mentioned "the ability for scientific and quantitative reasoning." The AACU summary of college statements talked about 'diverse disciplines' but made no explicit mention of science. The AACU summary statement mentioned science under the heading of "understanding and using multiple modes of inquiry and approaches to knowledge."

With the lack of consensus on the goals of a liberal education, it may be pointless to argue whether science is – or is not – a core liberal art. And even if science is viewed as a core liberal art, there is the question of whether science is functioning effectively in that capacity. When measured by the criteria of the Public Opinion Laboratory at Northern Illinois University, scientific literacy is found among 6% of US adults, 17% of college graduates (25% of college graduates in science or engineering, but only 10% among college graduates in education). See Steen (1991).

5. Findings

Despite the lack of consensus on what constitutes the liberal arts, we can draw some conclusions about the role of mathematics, engineering and science as core liberal arts based on current practices.

- Mathematics is clearly a core liberal art – at least as quantitative reasoning (QR), as quantitative literacy (Steen 2004a and 2004b)[17] or as statistical literacy (Schield 2004a and 2004b).[18]
- Engineering is seldom – if ever – viewed as a core liberal art even though 'technological literacy' was mentioned as an instance of an intellectual skill or capacity. This may reflect the historical lack of appreciation for the production of values for use as a skilled or intellectual enterprise rather than as an unskilled or manual enterprise. This lack of appreciation may also explain the ongoing tension between the liberal arts and the professions such as management and marketing.

[16] From *Contemporary Understandings of Liberal Education* by Carol Geary Schneider and Robert Schoenberg, undated, Association of American Colleges and Universities, Washington, DC. 1998

[17] See www.StatLit.org/QLit.htm and www www.StatLit.org/QL3.htm

[18] See www.StatLit.org/pdf/2004SchieldIASE.pdf and www.StatLit.org/pdf/2004SchieldAACU.pdf

- Science is sometimes viewed as a core liberal art – or as a component – in two different ways: as an area of study (scientific phenomena or diverse disciplines) providing material to be classified and integrated, and as a mode of inquiry. But in each case, science is a means to a higher end.

6. Increased Focus on Epistemology of Science

So why isn't science either regarded as – or functioning effectively as – a core liberal art? Certainly there has been enough time for science to prepare the arguments. But much written on this subject recently has focused more on non-epistemic matters: the role of the student (student-constructed learning, cooperative learning, active learning), the role of the teacher (the sage on the stage versus the guide on the side), and the focus on institutional integration (alignment of overall organizational intellectual mission with the choice of topics for general education). While these matters have their place, the thesis of this paper is that more attention is needed on epistemic explanations.

What is the epistemic justification for regarding the claims of science as knowledge? Asking such a question may provoke a negative response among two groups of readers:

- To those who are familiar with the history and philosophy of science, this approach may seem wrongly directed. Concerning content, few scientists are willing to argue that studying properties and behaviors of inanimate matter will provide much guidance on understanding complex biological systems – much less understanding human nature. Concerning the methods of science, evidence against success is provided by the efforts of the social sciences to adapt the methods of the physical sciences. Use the statistical reasoning pioneered in the physical sciences has not led to any major advances in understanding human nature in the social sciences, nor has the use of manipulative experiments in modern psychology. And concerning the categories of ideas, the history of philosophy is littered with the consequences of unresolved philosophical problems such as nominalism versus realism.
- And for those who see truth as relative and ideas as being continually overthrown, the idea of knowledge itself is questionable. Terms like 'certainty', 'truth' and 'cumulative knowledge' all presume a philosophical framework that they regard as either precarious or non-existent.

But readers in both groups are well aware that the terms of a disagreement can be radically changed by a shift in some of the fundamental ideas. Subtle changes in basic philosophical terms like 'essence', 'objectivity,' 'certainty' and 'truth' can open up new opportunities. Whether these changes are seen as a better integration of well-established ideas (by those in the first group) or as a paradigm shift (by those in the second group), the possibility of a major advance in explaining the continuing advance of cumulative knowledge in the physical sciences is always an open issue. And given the lack of success in other areas, it seems that this approach may provide a better opportunity for intellectual entrepreneurship.

7. Analysis of the Philosophical Methods of Science

We begin by focusing on the philosophical methods used to explain or justify knowledge claims by scientists. Content is too specific to serve as a theme for a liberal education (even though method without content is conceptually sterile). Unfortunately there are distinct viewpoints on the philosophical methods of science.[19] These include, (1) Science as an empirical process of integration with an accumulating weight of evidence.[20] (2) Science as a social process where consensus is a social construct and where the

[19] This classification is based on papers given at the 2004 meeting of the Philosophy of Science Association (PSA).
[20] "Science is orderly and dependable and progressive using procedural definitions, avoiding ambiguity, relating observation and experiment and theory and confirmation into a logical and coherent whole that leads to both under-

paradigm shift is the central element. See Kuhn (1962) and Baer (1992). (3) Science as a process of hypothesis, testing and refutation. See Popper (1959 and 1972). (4) Science as an extended form of deductive logic. See Pearl (2001).

Each view has its weakness in terms of showing how science produces knowledge. (1) The classical logical empiricist view lacks any solution to or resolution of the problem of induction so it can make no strong claim about producing knowledge. (2) The sociological view does not explain how paradigm shifts may still leave ‘old knowledge’ intact within a limited context (e.g., Newton’s laws still work in everyday life). Furthermore by focusing on the relativism of consensus and the lack of knowledge accumulation following a paradigm shift, the sociological view nullifies any claims for objectivity, certainty or knowledge. (3) The hypothetical-deductive approach is strong on identifying error, but has little – if anything – to say about the production of knowledge since weakly supported, but not-yet-falsified hypothesis are not quite the same as knowledge. (4) The deductive approach eliminates error in arguments by moving all the uncertainty into the premises so the truth of a conclusion depends entirely on the truth of the premise. In summary, each view is either unwilling or unable to make a strong case for saying that science produces knowledge.

Even though students may be epistemologically unsophisticated, they can tell that the difference between a theory (Darwin’s theory of evolution) and a law (Kepler’s law of planetary orbits). If science cannot offer a justification for its claims as knowledge, if these scientific claims are little more than a narrative spoken repeatedly and in unison by a small group of self-proclaimed scientists, then why should students to regard scientific claims as superior to those that these scientists consider non-scientific?

8. Analysis of the Objects and Operations of Science

Since the philosophy of science can become disconnected from the reality of science, it may be more useful to focus on the objects and operations of science. Consider these three. (1) Science operates using laboratory experiments – a powerful method of inquiry commonly used to obtain knowledge about the natures and causes of things. Because this method of knowing is so powerful, science deserves to be considered as a core liberal art. (2) Science deals with tangible objects. Science classifies these tangible subjects into categories or classes, identifies what is most fundamental or essential about a given class, and forms appropriate definitions of a given class of subjects. Because science unites tangible concretes with these basic operations of the mind, science deserves to be considered as a core liberal art. (3) Science deals with intangible objects such as gravity, magnetism, atoms, and black holes. Inferring the natures of such unobservables from their observable characteristics and behaviors is so essential to the sciences and is so important for the intellectual development of the mind that science deserves to be considered as a core liberal art.

Each of these brief arguments could be expanded and clarified. But our purpose is to look for weaknesses or defects in these arguments. If weaknesses or defects can be found, then we may have an explanation for the fact of science not being regarded as a core liberal art and we may have guidance on how to make science a core liberal art in the 21st century. Consider some plausible weaknesses in each argument. (1) The scientific method and manipulative experiments. Given the success that scientists have had in using manipulative experiments to determine the natures and causes of things, it seems almost inconceiv-

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standing and control” from de Boer (1991). In 1899, Huxley noted, “In teaching him [a student] botany, he must handle the plants and dissect the flowers for himself… Tell him that it is his duty to doubt until he is compelled, by the absolute authority of Nature, to believe that which is written in books.” (p. 11) able that this could be regarded as a negative or as a defect. But consider the position of those in the humanities who reflect often on the nature of the liberal arts. Manipulative experiments are all but irrelevant to the study of the human condition. While modern psychology has put experiments to good use, those in the humanities see a great deal of the human condition as being beyond the reach of psychology. (2) Science and tangible objects in developing intellectual skills. While this argument is often used to justify science in primary and secondary schools, it may be that this argument is too simple to be useful at the college level. The understanding of intangibles is so important in the life of the mind that this focus on tangibles may simply be misguided. (3) Science and intangibles in developing intellectual skills. This approach does not require manipulative experiments, and it certainly avoids having a primary focus on observerables. So what weakness or defect might it have? Much more investigation is needed on this question but there is a definite connection with the points made in the previous section involving the philosophical methods of science. So long as science is unable to mount a credible defense for producing knowledge concerning unobservables, so long as it continues to speak only in terms of theories, conjectures and not-yet-refuted hypotheses which may be overturned in future scientific revolutions, then science may have little to offer the humanities – since the humanities already have a full plate of theories, conjectures and hypotheses which seem to be overturned all too frequently.

In conclusion, the lack of consensus on the epistemic status of scientific claims may explain why science is not functioning effectively as a core liberal art. And without advances in the epistemology of science, it may be simply impossible to make science a core liberal art for the 21st century.

9. Strategic Importance of Science

The foregoing points may support the idea that the central role of science in the curriculum is at best an historic accident and is perhaps undeserved. Indeed if the stature of science among adults were the criteria, science might indeed be excluded from consideration as a core liberal art. If the level of scientific literacy among adults were the criteria, then science might be excluded from consideration as a liberal art. But before making any such rush to judgment, it is important to recall the amazing progress made in the sciences since the time of Tyco Brahe. With the inferences involving gravity, atoms, electromagnetic waves, DNA and elementary particles, science has built an edifice of knowledge that is cumulative, integrated and useful. Whatever mistakes have been made along the way (and these have occurred), they do not seem to have had the long-term negative consequences that such mistakes have had in education or the humanities.

By its success, science has provided evidence that it is using methods of forming concepts, principles and generalizations that integrate existing knowledge into new knowledge, and that provide the foundations for knowledge yet to come. Even though science has yet to produce a justification of what it does, it is continuing to produce evidence that what it does is justified to be called knowledge – as measured by the test of time. If science can better identify, justify and explicate what it does epistemologically, then science has the potential to become – and to function effectively as – a core liberal art for the 21st century.

10. Conclusion

Given that science is not generally regarded as a core liberal art, what can science do epistemically to remedy this situation? Given the inability of philosophy to deal with problems involving the nature of essence, truth, certainty and knowledge, it seems almost arrogant to think that any actions in that area might be productive at this time.

But philosophers and scientists are keenly aware that a small change in fundamental ideas can have a large effect on otherwise insolvable problems. The thesis of this paper is that an investment in the epistemology of science, risky as it may be, would – if successful – produce a change that could be far greater than that in any other area at this time. And without such a change, it may be that all other investments will be only modestly positive at best – and could be even harmful at worst – because they don't reflect an overarching goal and strategy that can – by its very nature – bring about the desired goal of making science a core liberal art for the 21st century.

Schield (2004c) has argued that there are some new developments in conceptual literacy – the study of concept formation and of inductive inference – that may make an investment in that area less risky and more likely to succeed.

11. Recommendation

As part of a broadly based effort to make science a core liberal art, there should be some support for an increased focus on conceptual literacy as the cornerstone for scientific literacy. See Norton (2003[21]) and Giere (1988 and 1999). This increased focus could involve three elements: (1) Focus more on the observational aspects of science where manipulative experiments are impossible (such as in astronomy or epidemiology). Science might also focus more on the idea of mentally controlling for relevant factors in observational studies (using comparisons, proportional reasoning and mathematical models) rather than focusing almost exclusively on the idea of taking physical or manipulative control of relevant factors in experiments. This might allow those in the humanities to see how the methods of science might be utilized in studying those subjects which ought not – or cannot – be reduced to objects of manipulative experiments. (2) Focus more on tangible observables as a stepping stone in arguing why some features are more fundamental, more essential, than others in understanding the natures and causes of things. The notion of what is essential should involve a crucial place in the formation of concepts – an essential part of a liberal education. (3) Focus more on unobservables and on generating inductive inferences as a guide for how this might be done properly in the humanities. Schield (2004) has argued that this mental activity is what should unite the study of the physical sciences with that of the human condition.

Focusing on these epistemic aspects of science may also remedy an apparent weakness in liberal education. A comprehensive longitudinal study of learning at the college level "found little evidence to suggest that attending an academically selective four-year institution had much impact on growth in critical-thinking skills during the first three years of college" (Pascarella, 2001, p. 22).[22]

If science could show the liberal arts how to better think critically about all aspects of reality, science might be responsible for upgrading the status of a liberal education to being both liberating and practical.

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[21] http://philsci-archive.pitt.edu/archive/00001446/
[22] www.cae.org/content/pdf/CLA.ConceptualFramework.pdf

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Appendix A. The 1892 Report of the Committee of Ten

In 1893, the "Committee of Ten" issued a report for the National Education Association recommending that science make up 25% of the high school curriculum. The quotes are from de Boer (1991).

- The Conference on Physics, Chemistry and Astronomy recommended that "fully half of the work in high school science was to be laboratory work" but that "students should not be encouraged to 'rediscover' the laws of science," Physics lab exercises should include (1) "measurements and calculations to determine the properties of objects and phenomena," and (2) "the verification of physical laws."
- The Conference on Natural History noted three goals in studying nature: (1) "to interest the children in nature," (2) "to develop certain mental abilities (or as the conference members put it, 'to cause them to form the habit of investigating carefully and of making clear, truthful statements, and to develop in them a taste for original investigation')" and (3) "the acquisition of knowledge" – knowledge "gained by personal experience" and "without the aid of a textbook." "Sixty percent of the time would be spent in the laboratory and entire course would be focused on the observations made in the laboratory." Since the biological sciences were largely descriptive rather than experimental (like physics and chemistry), "their primary use was to train the powers of observation, discrimination and classification." "Although such a course could easily lead to a focus on memorization and the acquisition of knowledge, the conference members insisted that the primary purpose of the course was not the acquisition of knowledge but the mental discipline and intellectual growth that came from careful observation of nature."
- The Conference on Geography (taken broadly as including physical geography, physiography, meteorology and geology) identified these primary objectives for study as "the development of (1) powers of direct observation, (2) the ability to form clear mental images and accurate conceptions of geographical features that were beyond the range of observation, and (3) reasoning powers." In developing reasoning ability, "students should be led to an understanding of the reason of things," "the evidence leading to the conclusions and not simply the conclusions." "One caution they offered was that the emphasis on cause and effect relationships should be in relation to the ability of the students to reason abstractly. Overloading the student with more than they could handle would lead to memory without understanding."

[30] Web-copy at www.aacu.org/publications/practicing_liberal_education.cfm

Appendix B. Twentieth Century Support for Science as a Core Study

As before, the quotes are from de Boer's (1991) excellent history of science education.

In 1902, Alexander Smith noted two reasons for teaching chemistry: "One was to acquire knowledge, that is, to understand the subject of chemistry as fully as possible. The second was to develop the ability to think, which according to Smith meant the ability to compare, to discriminate, and to reason inductively." "Smith argued that the laboratory should be used in at least two different ways. First it was a place for the verification of chemical principles, and second, it was a place for independent discovery." "Appealing as the method [using lab for independent investigations] sounded, Smith believed that it took too much time and did not furnish the knowledge of chemistry that was needed at the secondary level.

In 1902, Hall identified three separate theories of laboratory instruction. The first was the discovery, or heuristic, approach; the second was the verification approach; and the third was the inquiry [guided discovery] approach." Hall noted their weaknesses. "The discovery or heuristic approach was an inductive strategy in which students were expected to discover the important facts and principles of science largely on their own. As with so many formulas for good teaching, the approach had a tendency to become mechanized and used in an unthinking way." The verification approach "that asked students to confirm some scientific fact or principle in the laboratory was equally deficient because it developed an unscientific attitude." "Hall also felt that learning by experience was too slow."

"In the relatively short time between 1893 and 1920, the justification for science in the curriculum had shifted from an argument based almost exclusively on science's ability to develop one's intellectual skills … to one based on science's ability to develop an individual who would be a happy and contributing member of society." The 1920 statement of the science subcommittee identified five major goals. "First, there was the ever present interest in improving the general welfare of society through education. A second goal of science teaching was to develop science-related avocational interests and an enjoyment of nature, and a third was to interest students in further study of science. A fourth goal was that science teaching should develop the students' abilities to observe, to make careful measurements of phenomena, to classify observations, and to reason clearly from what had been observed." The fifth goal, strongly emphasized, was "the full understanding of the principles of each separate science field." "It was the fifth goal that, more than the others, determined the teaching strategies that would be used."

There was concern by the science subcommittees on the misuse of the laboratory. "The biology subcommittee was concerned that too much time was wasted in the laboratory on useless activities, and not enough on the development of important ideas." The chemists noted that "too many experiments involve repetition of work described in the text or have no outcome beyond the mere doing and writing in the notebook." "The scientific subcommittees also talked about developing such mental abilities as inductive reasoning and observation, but this goal did not have prominence that it had when the Committee of Ten touted the benefits of laboratory instruction in 1893." "In all of the science subcommittees there was a firm belief in the value of student interest." "If the student was not motivated to know, teaching would almost certainly fall on deaf ears."

Appendix C. AAPS and Science Literacy

In 1985, the American Association for the Advancement of Science (AAAS) founded Project 2061[31] "to help all Americans become literate in science, mathematics, and technology."[32] In 1989, the AAAS established science

[31] www.project2061.org/publications/sfaa/default.htm and www.project2061.org/default_flash.htm

[32] Project 2061 began its work in 1985-the year Halley's Comet was last visible from earth. Children starting school now will see the return of the Comet in 2061-a reminder that today's education will shape the quality of their lives as they come of age in the 21st century amid profound scientific and technological change.

literacy goals in the publication *Science for All Americans*.[33] In 1993, the AAAS published *Benchmarks for Science Literacy*[34] to translate these science literacy goals into K-12 learning goals.[35] With recent publications like *Atlas of Science Literacy*[36] and *Designs for Science Literacy*,[37] Project 2061 continues to influence the reform of science education. The *Atlas of Science Literacy* is designed "to help educators gain insight into the connections among benchmark ideas. This atlas provides, "a collection of linked maps that depict how students might grow in their understanding and skills toward particular science literacy goals. These maps display not only the sequence of benchmark ideas that lead to a goal, but also connections across different areas of science, mathematics, and technology, and how ideas come together in sophisticated understanding."

The following summarizes the themes presented in the Atlas of Science Literacy. Project 2061 defines science literacy broadly, emphasizing the connections among ideas in the natural and social sciences, mathematics, and technology. *Science for All Americans* "is based on the belief that the science-literate person is one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes." *Science for All Americans* includes specific recommendations for learning in the following areas:

- *The Nature of Science* includes the scientific world view, scientific methods of inquiry, and the nature of the scientific enterprise.
- *The Nature of Mathematics* describes the creative processes involved in both theoretical and applied mathematics.
- *The Nature of Technology* examines how technology extends our abilities to change the world and the tradeoffs necessarily involved.
- *The Physical Setting* lays out basic ideas about the content and structure of the universe (on astronomical, terrestrial, and sub-microscopic levels) and the physical principles on which it seems to run.
- *The Living Environment* delineates basic facts and ideas about how living things function and how they interact with one another and their environment.
- *The Human Organism* discusses human biology as exemplary of biological systems.
- *Human Society* considers individual and group behavior, social organizations, and the process of social change.
- *The Designed World* reviews principles of how people shape and control the world through some key areas of technology.
- *The Mathematical World* gives basic mathematical ideas, especially those with practical application, that together play a key role in almost all human endeavors.
- *Historical Perspectives* illustrates the science enterprise with ten examples of exceptional significance in the development of science.
- *Common Themes* presents general concepts, such as systems and models, that cut across science, mathematics, and technology.
- *Habits of Mind* sketches the attitudes, skills, and ways of thinking that are essential to science literacy.

[33] www.project2061.org/publications/sfaa/default.htm
[34] www.project2061.org/publications/bsl/default.htm
[35] www.project2061.org/tools/benchol/bolintro.htm
[36] www.project2061.org/publications/atlas/default.htm
[37] www.project2061.org/publications/designs/default.htm