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Diversity in American Biology, 1900-1940

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ABSTRACT – This paper argues both that the decentralized and democratic context in the United States prior to World War II encouraged the development of diverse approaches, programs, and institutional supports for the biological sciences, and that the resulting pluralism is consistent with the complex and messy ways that science is used in a democratic society. This is not a claim that only U.S. science experiences such diversity, nor that the way science plays out in our American form of modified constitutional democracy, are unique. Rather, my intention is to underline the particular character of the diversity and its implications for science and to begin further discussion of this phenomenon. I challenge others to pursue comparative analysis for other places and times, so that we can begin to explore more deeply what meaning this diversity – or the lack thereof - holds for science more generally.

Background

Two themes drive this paper. First, that the decentralized and democratic context for the biological sciences in the United States prior to World War II encouraged the development of diverse approaches, programs, and institutional supports. Second, the resulting pluralism is consistent with the complex and messy ways that science is used in a democratic society. While the focus remains on the period prior to World War II, the shifts to increased centralization and coordination in recent years raise questions about the changing uses of science in society. I am *not* claiming that only U.S. science experienced diversity, nor that the particular American form of modified constitutional democracy uses science in an absolutely unique way. Comparisons to other countries and other contexts remain for further research. Rather, I seek to point out a general result (diversity) and briefly to outline some contributing factors and some consequences. The first part of the paper, therefore, establishes the existence of diversity and emphasizes the way that a pluralism of alternative research programs – in which biologists pursued a diversity of research with differences in such factors as questions asked, research methods, approaches, and views about what to count as evidence and what to count as an answer to a question – helped enrich American science. Thereafter, a variety of factors such as shifts to more centralized funding and concerns to establish the social value of science changed the dynamics as well as the role and place of science in American society.

The first section explores major factors that shaped the diverse nature and role of American science before World War II, with a focus on education, a scientific ethos, expertise, institutions of research and education, and the biomedical sciences. Then, I offer selected examples to show how a diversity of research programs arose within their different contexts. In some cases, competition resulted and produced lively results. In others, specialization and dividing up of research avoided competition but still produced a pluralism of different ideas and different epistemological views about how best to go about doing what they regarded as 'good science'. Finally, I ask whether this pluralistic tolerance of diversity and the resulting competition was a good thing for science. What does this tell us about how science develops and its role in our particular form of democratic government. This is an interesting problem because theoretically a democracy allows all participants an equal input (through representatives and as shaped by the constitution). Yet science is meritocratic and creates experts and leaders who are, by virtue of the scientific work they do, regarded as better or more important than others. The second part, then, reflects on this apparent puzzle.

The second section also notes that after World War II, Americans have exhibited some ambivalence about science, feeling both enthusiasm (in the Sputnik era) and fear of the products of science (from the destruction by bombs and radiation and from destruction of the natural environment). Furthermore, the centralized support of scientific research with the National Science Foundation and public support of that commitment have changed the dynamics of science as well as its social setting (Bush 1945; Sigma Xi 1995; Reingold 1991). In particular, as the NSF and other federal research-supporting agencies have grown, they have to a considerable extent shaped what scientific work gets done – and by which scientists as well as its rate and volume of scientific activity. Yet diversity still prevails – within the new constraints.

I. Science in Society before World War II

What major factors shaped the pluralistic nature of science and its role within American society prior to World War II? The following five separate, but interrelated, forces are the most important: public education; the rise of a scientific ethos and expertise; a rising regulatory mentality; availability of pools of 'disposable' wealth; successes in the biomedical sciences

Public Education

In the seventeenth century, the various colonial governments followed the British model and encouraged public education. Especially in the New England colonies, taxes supported schools and local governments oversaw what was taught there. The founding fathers held the view that educated individuals (or at least white males with sufficient wealth) would make better citizens, presumably able to make wiser decisions and to contribute productively to society. When the United States was established, these duties remained with the states, so that from the beginning the educational system was highly decentralized. The eighteenth century brought further decentralization, with the rise of local, private, and church-run schools. Even the rise of public elementary and secondary schooling in the nineteenth century gave control to local governments and businesses. This added to the rich diversity of educational institutions.

Most dramatically came the rise of state universities (funded in part by the federal Morrill Land Grant Act of 1861 that provided national funding for a range of especially agriculturally-oriented and public universities) (Dupree 1957). In addition, there arose numerous community-based colleges (often church-run), complemented by junior colleges after 1910 and by technical and professional schools (covering a range of areas from agriculture to mining and medicine). Normal schools also developed early in the twentieth century to produce a supply of qualified and trained teachers. In addition, many communities sought to improve their citizens with local Ladies Clubs, Book Clubs, Grange Societies, and others. The general results were both a valuing of education by a wider range of people and demand for that education. Thus, the continued expansion of diverse educational institutions and commitment to an educational ethos strongly influenced the values of a growing American public.

Immediately after World War II, the 'G.I. Bill of Rights' provided for college education at public expense for returning soldiers. This move affected millions of young men and women who would not have had the access to, or perhaps the interest in, pursuing higher education. It also reinforced the educational ethos and emphasis on practical scientific values and beliefs in the progress to be made through science. These opportunities created a background against which diverse scientific programs could develop as they produced a wide variety of institutional settings in which science could be done.

Rise of scientific ethos and expertise

By the 1890s, Americans were beginning to follow their German counterparts in accepting a scientific and research ethos. With a strong pragmatic tradition, engineering had achieved high status so that technological skeptic and historian Henry Adams noted the rise of a scientific epistemology with some concern. In his 'Autobiography," Adams noted his own reflections that 'Suddenly, in 1900, science raised its head and denied [any supersensual factors]' (Adams 1918, p. 452).

By the 1930s, civil engineering took on a special role as the U.S. established the Federal Emergency Relief Administration to help provide relief to the many people unemployed and dislocated by the Depression (Dupree 1986, pp. 361-162). At their peak, civil works programs hired over four million mostly young men in 1933. The teams of often untrained workers built and repaired roads, bridges, schools, sewage systems, dams and other public projects that placed engineering in the public eye. Engineering is, of course, not precisely the same as science. Yet science benefitted in numerous ways from the successes and increase in visibility for the practical application of expert thinking.

Leading the way in reinforcing the perception of great progress to be made through science came such research-oriented institutions as the Johns Hopkins University in Baltimore, begun in 1876 with great ceremony and emphasis on a new research approach based on scientific thinking. The first Ph.D. degree in the United States had been awarded by Yale University's Sheffield Scientific School in 1861 and the research emphasis that this professional degree represented expanded quickly. New universities appeared, such as Clark University in Worcester, Massachusetts (outside Boston, established in 1887 as a graduate institution), Bryn Mawr College (in Pennsylvania, founded in 1880 for women to pursue research opportunities and closely related to Johns Hopkins), the University of Chicago (founded in 1891 as a 'western Yale'), Stanford University (begun in 1885 as the first major California research-oriented university), and others (Coe 1950; Crampton 1942; French 1946; Newman 1948; Romer 1948; Ryan 1939).

Older universities such as Columbia University (in New York City), Harvard, and Yale Universities (which had featured graduate programs within their scientific schools but expanded those research programs to all fields and embraced scientific thinking at the undergraduate levels as well), and the University of Pennsylvania all extended their research emphasis and also their scientific programs by early in this century. They endorsed what can be thought of as a scientific epistemology. That is, they endorsed the view that discoveries to be made through scientific research into aspects of the natural world would, in fact, yield desirable knowledge.

The process was reinforced by the Flexner Report of 1910, a widely-circulated report that called for reform of medical schools to make them scientifically based, covering the range of sciences (Flexner 1910). A note in *The Nation* in 1928 suggested that 'A sentence which begins "Science says" will generally be found to settle any argument in a social gathering, or sell an article from toothpaste to a refrigerator'. Furthermore, as the Science Service put it in a 1921 article: 'In a democracy like ours it is particularly important that the people as a whole should so far as possible understand the aims and achievements of modern science, not only because of the value of such knowledge to themselves but because research directly or indirectly depends upon popular appreciation of its methods. In fact the success of democratic institutions, as well as the prosperity of the individual, may be said to depend upon the ability of people to distinguish between science and fakes, between the genuine expert and the pretender' ('Science in American Life' 1996).

So science brought a research focus and an emphasis on exploration and progress. In doing so, it brought an accompanying emphasis on those doing the exploration and making the progress: on the scientists and scholars, the experts. Hence an emphasis on expertise. In theory, at least, one became an expert in this scientific arena because of one's study and research rather than one's social or economic position. It seemed to offer the most deserving the opportunity to become experts through education and hence appropriately democratic, though it also insured that those without accesses to education could never join the new scientific elite. Again, a diversity of opportunities resulted. And it became possible to have a scientific research career.

Science also became terrifically popular with the public. Louis Agassiz in the cities and others on the Grange circuit through rural America, took enthusiasm for science and the scientific expertise to a receptive public eager for progress and solutions to problems. Over time, this led to periodic over-selling, disillusion, and ambivalence about what science can do (Burnham 1987).

A rising reform spirit

Moving away from the emphasis on individuals and the attitude that every citizen must beware any risks for himself or herself (an emphasis on individual rights and responsibilities typical of the nineteenth century era of Jacksonian democracy), the Progressive era early this century brought increasing interest in social protections. It seemed that the rapid rise of city populations and of available technologies was rapidly surpassing the ability of individual citizens to understand them and to know enough to make wise choices. Local governments and labor movements also sought to protect the public - or at least to appear to be doing so. And the rosy promise of science apparently offered solutions.

After 1900, the American Medical Association launched major attacks on proprietary medicines and self-medicating (Burrow 1963). These physicians obviously preferred that people hire a physician, and as formal medicine seemed to offer more expertise and the ability to cure more diseases and to solve more problems, they enlisted wider support for their reform efforts. Journalistic 'muckrakers' contributed. Articles in widely-popular publications like the *Ladies Home Journal* urged women to avoid impure foods and medicine. *Collier's* joined the call for regulation with articles such as Samuel Hopkins Adams's 'The Great American Fraud'. This, with such widely-read works as Upton Sinclair's damning portrayal of the meat-packing industry in *The Jungle* contributed to the public movement that soon led to the Pure Food and Drug Act passed by Congress in 1906 (Young 1989; Starr 1982). The decision to pass federal regulation, relying on experts and scientific standards to protect society, illustrates this era of reform.

Regulation implies standards, and the need to produce and certify experts to set and police the standards. Further research could discover new 'facts' about existing hazards and risks and lead to new standards for water quality or food cleanliness or coal purity. Others considered seed purity and the relative value of pure and hybrid crops, for example. For many it seemed only a short logical step to acceptance of the concept of racial purity and enactment of public health and eugenics laws to enforce protection of society from impure or unhealthy heredity or bad 'blood' or bad behaviors. Eugenics, social Darwinism, intelligence testing, and efforts to eliminate 'waste' of all sorts responded to the call for reform. Thus, the creation of new knowledge enabled social uses of the knowledge, which in turn reinforced the scientific culture and the experts who had produced the knowledge. In the background lay a basic assumption that the knowledge thus gained, scientifically through research, remains reliable and deserving of a special status as definitive – even though application of the knowledge and selection of which knowledge to develop might require considerable interpretation and even regulation.

'Disposable' Wealth

Though still quite small in numbers of participants and in overall cost, the education and research enterprises had begun to grow by 1900. Growth required investment of capital, and fortunately a few American entrepreneurs had succeeded in capitalizing on human and material resources to accumulate such capital. Successful families, such as the Rockefellers, Carnegies, Vanderbilts, Stanfords and others put some of that capital to work promoting public education and science by building museums, universities, and libraries.

Of course, a wide range of interpretations of such actions remains possible. Some historians deplore what they see as the exploitation of human workers and as the unjustified acquisition of material wealth. Others point to a cynical interpretation for such investment: it provided a greater pool of citizens inclined to share the values of the 'robber barons' and diminished the number of potential critics. Some feminists explain that women were typically not in the first group of capitalists, who were amassing wealth. But increasing numbers of women were sharing and inheriting significant accumulations of wealth, which they put to good use. For example, wealthy women donors gave the Johns Hopkins Medical School the courage to push for stronger scientific reforms than they would have otherwise been willing to try (Fleming 1954, pp. 96-99).

This accumulation of disposable wealth and the efforts to use it for social advantage continued through the financially upbeat 'roaring 20s'. The accumulated wealth could be put to work to promote research while also helping to establish public welfare and social order. Strong and powerful leaders such as Mary Lasker led the way with significant fund-raising for such special diseases as polio (National Foundation for Infantile Paralysis 1937), which inspired the eventual creation of the National Heart Institute in 1948 and the various separate disease-specific institutes were coordinated as the National Institutes of Health (Starr 1982, pp. 342-344).

Success and Controversy in the Biomedical Sciences

Against this background, the life sciences made significant strides in medicine, genetics, and evolutionary studies. The germ theory of disease provided the late nineteenth century with a theoretical framework and a laboratory approach such that it seemed only a matter of time before we had discovered the germ causes of all diseases. Just enough successes with vaccines or treatments and the eventual development of effective antibiotics reinforced the conviction that medicine was on the verge of solving our problems and making life 'safe'. Medical research thus took on a special 'halo effect' that benefited the biological sciences generally.

The Rockefeller Foundation provided the most dramatic support through the early decades of this century, supplemented by smaller efforts from the federal government through The National Research Council. Then larger fund-raising efforts such as the March of Dimes targeted a 'war on polio' and brought great attention and enthusiasm from a wide range of citizens – efforts that soon led to the larger federal programs through the National Institutes of Health and National Science Foundation after World War II (Kohler 1991).

This excitement about the biomedical sciences was brought to the general literary public by writer Sinclair Lewis in his novel *Arrowsmith*. There, the country doctor Martin Arrowsmith made his way to the fictional fancy New York City research center called the McGurk Institute. Lewis reflected and helped to shape the public perception of scientific advance with his description.

Genetics research made slow progress but began to gain attention for its potential especially with the work of Thomas Hunt Morgan's fly group. As they developed techniques for measuring distance of unit factors along chromosomes, and as they developed concepts of non-disjunction and linkage, they also gained tremendous support for their research. As Garland Allen has outlined in his biography of Morgan, and as Robert Kohler has argued in his recent study of the Cal Tech fly team, the collaborative nature of their work combined with enthusiasm for biomedical promise and other institutional factors to accord this research high status (Allen 1978; Kohler 1994). The successes reinforced enthusiasm for biomedical research.

Evolutionary biology also gained attention as more study of heredity and particularly Mendelian-chromosomal heredity – combined with population studies – provided ways of thinking about the sources of variation necessary to make a Darwinian evolutionary system work (Smocovitis 1996; Mayr 1982). Yet evolution brought controversy. By the 1920s, evolutionary biologists were moving ahead; science held a high status among Americans, but paradoxically, religious fears also reached a peak in the same period. The state of Tennessee's much-publicized Scopes Trial brought these fears to a crisis.

In 1925, a high school teacher, John Scopes in Dayton, Tennessee, was teaching evolution in his biology classes. Yet a new state law prohibited teaching in public schools 'any theory that denies the story of the divine creation of man as taught in the Bible'. It was illegal to teach that man descended from other animals. This strong statement immediately brought the attention of the American Civil Liberties Union, a group devoted to the protection of individual rights and freedom of expression of ideas. They challenged the laws, supported Scopes when he violated the law, and thereby provoked a dramatic public trial in court. The trial received tremendous media attention, with newspaper reporters telegraphing every detail back to their newspapers all over the country. This was a dramatic clash of fundamental values: do we believe science and scientific experts or the Bible? In the narrow sense, Scopes ultimately lost since he had violated the law, but the case raised central issues about public education and science and religion. On a broader view, science won – even though the Tennessee law remained on the books until the 1970s and has been revived in the last couple of years (Ginger 1958; Larson 1997).

Such controversy and apparent contradictions are often difficult for those outside the United States to understand. Why so much enthusiasm for science generally and yet so much fear of particular ideas? American fundamentalist Christians have insisted on dichotomizing the discussion, insisting that a creationist set of values necessarily conflicts with materialist Darwinian evolution. We have a conflict of fundamental values systems, and a conflict of epistemologies: does science or revealed faith produce knowledge and even 'truth'? This shows that while Americans are enthusiastic about science overall, and while they support the biomedical sciences enthusiastically, they remain ambivalent and uncertain about some of the messages of science.

These five factors demonstrate the establishment of science and of an epistemology that emphasizes scientific research as the appropriate way to produce useful and publicly valued knowledge. The diversity of patterns of public education, scientific thinking, social concerns, funding, and scientific successes produced a richness of diverse emerging scientific institutions and opportunities.

II. Diversity and the American Way

We thus see the convergence of factors that have raised scientists to the status of experts with high social importance, and with institutions welcoming and supporting them. We also see that the co-existence of different and competing values (where science conflicts with other values, and scientists disagree among themselves) within American democratic society has led to episodes of confusion and competition. Particular scientific advances have not always prevailed in this context, even while a general scientific ethos has. How has this diversity of values played out? Americans remain committed to an ideology of open competition (even when they do not actually carry it out) and we live in competitive, adversarial legal and political systems. In contrast, science supposedly works cooperatively, so how do scientists work in this apparently contradictory environment? Let us look at some examples.

The University of Chicago provides a good case, reflecting the vision of one of the early American biological leaders, Charles Otis Whitman. Whitman made his administrative impact as first director at the Marine Biological Laboratory, head of biology at Clark University, and department head for the biological sciences at Chicago – all important institutions for shaping American biology (Ryan 1939). He tried to address the apparent contradictions by developing a cooperative model.

Whitman envisioned biology, with the various more specialized areas coordinated together as an organized, research-oriented whole. He regretted that Americans had not really adopted this model and felt that 'Argument will never dislodge them; they can be reached only through the leavening influence of high examples. A single biological department organized on a basis broad enough to represent every important branch at its best, and provided with the means necessary to the freest exercise of its higher functions, would furnish just the example we stand in need of' (Whitman 1887, pp. 516-517). The ideal should be 'Specialization and Organization', as Whitman emphasized in his inaugural lecture at the Marine Biological Laboratory in 1890. Biology should be like the living organisms, where individual cells specialize but the coordinated whole functions to do much more than any individuals, for 'It must be evident to every one who is capable of understanding the situation, that *union* is just as essential a part of the law of progress as division. If specialization is a necessity, so is organization. But there is this difference between the tendencies, – that the one precedes the other and comes into recognition first. Specialization has already forced its way to the front, and is nearly everywhere recognized as a necessity; organization follows, but lags lamentably behind the needs of the times' (Whitman 1890, pp. 22-23). The new University of Chicago offered the opportunity to pursue Whitman's ideal.

Yet, as with most ideals, reality pushed in different directions, and more competitive models prevailed. The University did not, in the end, provide all the support that Whitman had expected. As opportunities expanded and the number of researchers entering the biological sciences grew, specialization was relatively easy while cooperation was not. By 1900, it had already become difficult to remain fully informed in all areas of biology. The diversity and decentralization of the system allowed specialization without there being any authority to insist on coordination or cooperation. When faced with the mandate to be productive, to produce more scientific knowledge in particular, and to become an expert, researchers emphasized specialization rather than cooperation.

The result was considerable overlap, duplication, and competition of research efforts. Whitman tried to make this process efficient, but one person in such a diverse system could have only limited effect. While training graduate students in the 1890s to take up the tracing of cell-lineages in development, Whitman set them working in cooperation, along parallel paths, asking similar questions about different organisms. As they found jobs elsewhere and set up their own research programs, however, they began *de facto* to compete for their own graduate students and for leadership positions professionally. While specializing and cooperating, as Whitman encouraged, they also engaged in competition and diversification.

The earlier ideal of cooperation thus gave way to the realities of competition and diversity. While Yale University had emphasized evolutionary biology, in 1907 they hired medically-oriented Ross Harrison who specialized in neuroembryology and emphasized that area and related areas for decades. He never saw the point of hiring a geneticist at Yale, though he remained chair of the biology department until mid-century, yet others did.

Columbia, in contrast, stressed genetics – as well as cytology and evolutionary morphology, but not neurobiology or general physiology.

Henry Fairfield Osborn put his personal stamp on the Columbia department as well as on the American Museum of Natural History, which he also directed (Rainger 1991).

Pennsylvania emphasized evolutionary biology, Chicago a combination of morphological and physiological zoology, and Illinois pursued agriculturally-related breeding studies, to cite a few examples. The Marine Biological Laboratory focussed on whole-organism studies in embryology, morphology, and related areas, while the Cold Spring Harbor Laboratory emphasized evolution and led to a special program in 'experimental evolution' (which meant eugenics) by director Charles Davenport. Meanwhile Friday Harbor Laboratories in Washington state and the University of Chicago soon developed ecological studies, in different ways. The agriculture programs and schools inspired by the Morrill Act encouraged practical results, as did private research institutions and medical school research enterprises. Each had its defined mandate, and the directors and trustees might seek to find an unoccupied niche in which to excel or might engage in competition in a more crowded arena. Records of the various institutions reflect their searches for a defined place in the competitive market of diverse approaches.

Thus, in the first half century of American biology, we see the emergence of a wide variety of American research programs and departments. As James Watson recorded in his popular book, *The Double Helix* (1968), he found the British system odd in contrast. Himself an American trained at Indiana University, he was accustomed to such competition and the freedom to explore whatever research areas one wished. He was astonished and dismayed to find that the British system expected specialization instead and sought consciously to avoid duplication. He regarded competition as desirable and healthy, as it pushed researchers on to achieve more in order to 'win' whatever prized knowledge they sought.

III. Competing Values

With expanding resources, this competition might indeed seem productive. Yet as resources declined and the demands on any institution expanded, the effect was less clearly positive. On the surface, this seems like an inspiring system and it embraces the American democratic spirit of free enterprise and open competition. Yet often, as institutions faced with limited resources sought to define their particular area of concentration, individual researchers found that they were expected to play a different role than the one they had assumed. Perhaps, as an example, they were forbidden to teach evolution because of a strong creationist feeling among the university's leaders. Or they might be instructed to pursue practical, applied work of a particular sort in response to market pressures. Competition among individual scientists might make them either conform or lose their positions since there were others available to take their places; competition among institutions or programs might be seen as producing a distinctive character in different places as each sought to establish its own identity. Perhaps researchers might be urged, let us imagine, to take up some currently trendy research problem or approach or to give up some controversial line of research because of competition from others pursuing a more acceptable line of research.

The concept of academic freedom arose in the early part of this century because of political efforts to restrict the teachings and research of faculty members, and researchers argued for the right to pursue their chosen individual lines of research with the resulting institution of tenure to protect that presumed right. Yet there is no protection for the untenured (typically the first six or occasionally up to ten years of a scholar's career at one place) and institutions can apply pressures to direct the research in some directions rather than others. It is less obvious in the face of declining support for scientific research why individual researchers ought to have the right to choose whatever research area they want rather than being expected to remain responsive to the dictates of whomever is paying the salary – particularly if that purchaser is the 'public'. through federal or state government grants and contracts. This discussion about rights and responsibilities of researchers surfaced in the 1930s as it has again in the 1990s, largely for economic reasons. Economic pressures, as scientific research became more expensive and required outside funding, play important roles here and can diminish – or stimulate – competition and its effects.

Is competition good for science? Evidently, yes and no. It has produced lively interchanges and heated discussions with intense productivity in the relevant fields. Such intentional competition can be good. Or competition can be unintentional, and still valuable when competitors do not even know of each other's work until late in the process. This may have a neutral effect but may be good if it leads to different productive ways of approaching a problem or generating new knowledge. Competition can promote creativity and diversity. A plurality of approaches may therefore produce ideas that fit productively together, even when they overlap and compete in subtle ways.

Yet competition can also breed inefficiency, since duplication obviously costs twice as much. Why fund multiple electron microscopes, the Rockefeller Foundation might have asked, when one would have done (Bechtel, in press). But what would it have done? Instead they decided to fund several and embraced the idea that different people in different institutions with different research agendas could make productive use of the multiple machines. Local factors apparently set the research efforts on different courses in these cases, since the local 'ecology of knowledge' creates multiple different opportunities. Diversity produces differences, which might be desirable in an ideal world, but these will be expensive. How can a nation afford to pay more than one researcher to carry out the same scientific research project? Indeed, given all the possible scientific research that could be done, critics might well argue that we should divide up the work, specialize and cooperate to avoid all duplication and competition.

A key consideration here, then, is the extent to which the research effort is coordinated or even centralized – and the effect of centralization or decentralization. There is no natural force for humans always to centralize, it seems, as we see with the recurring breakdown of large political and social unions. Rather, lack of central control allows individual creativity and expression of values to emerge and develop. In prosperous times, this may seem natural and ideal. Individual variation seems good. Yet this lack of central coordination allows the inefficiencies and duplication that, in times of limited resources, seems wasteful and problematic. Americans have retained their ideological conviction to embrace competition and diversity. It fits with the American idea of democracy, where all are supposed to have a voice. Yet they have also moved toward coordination and cooperation at various times and in various ways. This fits the idea of a representative and constitutional democracy, guided by overriding central principles and a system for legislatively and judicially adjudicating among competing claims. There are challenges for such a system.

The fact that the United States is a representative constitutional democracy raises special questions. In such a constitutional democracy, in theory the constitution sets the parameters for legal action and the various branches of government represent the interests of the citizens. Of course those citizens often have conflicting interests, and the judicial system is set up as an adversarial system in which opponents argue cases in order to allow adjudication among competing interests. The system, at least in theory, encourages expression of diverse individual interests, including but not preferentially including, scientific interests.

That raises several issues relevant to our understanding of science and its place in society. First, science should not obviously have any special or privileged status socially or legally. Second is the result that this attitude promotes diverse individual interests, encouraging scientific development and creativity through competition and diversity. These expectations, however, lead to two puzzles. First, given that it supposedly has no special status in a democracy, how did science gain ascendancy as a superior form of knowledge such that scientific experts have come to be regarded as providing compelling and decisive, that is uncontestable, evidence in many court cases? Second, how was it that such factors as funding mechanisms, institutional considerations, and academic migrations eventually actually reduced (or changed) the expected competition – and what effect did this have on the science?

At root lies the complicating fact that American science is done in the context of an interesting blend of contradictory values: the democratic political system with its reportedly representative methods of hearing and adjudicating among competing claims of all citizens, combined with an acknowledgment within the scientific community that all voices are not really equal since some are accepted as experts for a range of issues. This tension between democracy and expert superiority has received considerable discussion in recent years, and it has begun to shape the character of the scientific work done in some areas such as human genetics[1] (Maienschein et al. 1997).

What are we to make of this? Evidently science such as genetics is taken as having a high epistemological status in the courts and among policy-makers and educators in the United States. Yet science such as evolution is questioned and even rejected. Thus, science does not always prevail. The diversity of values and the decentralized legal system allows such apparent contradiction and raises many challenges. We begin to see how factors that have produced a 'central dogma' of authority for science (or engineering) and have diminished competition from other conflicting value systems have promoted the high value and status of the field as privileged knowledge. In other cases where several contested values have nonetheless persisted both within the sciences and with external social forces, science holds less

[1] Such issues were discussed at a recent National Science Foundation-funded workshop on 'Biology and Law', held at Arizona State University in March 1995, with a second follow-up workshop in May, 1996 and funded by the National Science Foundation. See workshop report 'Biology and Law: Challenges of Adjudicating Competing Claims in a Democracy,' published for the National Science Foundation, 1997. Revised and reprinted in *Jurimetrics* (1998): 151-181.

epistemological force. Diversity of scientific views is matched by diversity of competing value systems overall.

Conclusion

American biological science is not one thing. It is, rather, a patchwork of competing and overlapping views sustained by a patchwork of overlapping – and competing – schools, sources of funding, and social institutions and values. This overlap, this competition, is chaotic and costly. But it is also what gives American science its vibrancy. In attacking scientific problems in a variety of ways, American biological science has progressed further and faster than one neatly organized, narrowly-focused organization could have done. Just as the natural world looks hopelessly inefficient, with its diverse and redundant species competing for scarce resources, we can see an underlying subtle order, a system for coping with and producing adaptive change.

Perhaps it is not so surprising that the same sort of non-centrally-directed diversity can work well in science. It is worth reflecting on the trade-offs of more or less coordination in science and of encouraging more or less diversity and competition. Our current system promotes diversity with its many universities, state and local control of education, federal funding by a variety of agencies that are authorized and funded by several different committees of the U.S. Senate and House of Representatives. Periodic calls, typically made in the face of shrinking resources for science, for more coordination and efficiency, have led some to suggest that we need a few selected top tier research universities. Others would serve as providers of undergraduate education and as support institutions. Such suggestions typically come from leaders of the established institutions that receive the most money already and hence are strongly self-interested. As a faculty member at one of the most recently-designated Research I universities in the United States, I think it is clear that encouraging diversity, competition, and adaptation to changing and challenging conditions promotes creativity and flexibility. And that is a good thing, despite some inefficiencies, overlap, and redundancy along the way. There is, indeed, grandeur in this view of life, with its tangled bank and evolving beauty.

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