be subjected to test. This state of things need not be considered as unsatisfactory, if a liberal interpretation is given to the notion of empirical content. Furthermore, no change in this practice may be expected unless we succeed in characterizing social space and in giving it an appropriate place in the construction of economic theory. Whether this is feasible or not cannot be settled until more effort in this direction has been exerted.

### Notes

1. This statement is restricted to what may be called *positive economics*. The branch of economics dealing with normative propositions, known as *welfare economics*, does consist of pure deductive systems.
2. Strictly speaking, the $F_1$'s are not relations because they have not been completely specified. This problem will not occupy us here.
3. The $r^{th}$ social space may be thought of as the $r^{th}$ subset of all the possible states of the world. These are rather involved notions, but it would take us too far afield to attempt further elucidation in this article.
4. In the philosophical literature the distinction between explanation and prediction is of minor importance. An explanatory device is generally considered to be capable of prediction and vice versa. The claim made in this article that models are *strictly explanatory*—that is, incapable of use as predictive devices—stems from the assertion that there exists a class of non-L-determinate statements which may be confirmed, but may *not* be rejected, by reference to empirical evidence.
5. This procedure leads to the formulation of a system of difference equations. We could, of course, achieve the same objective by formulating a system of differential equations.
6. The notion of dynamic stability is far too complex for discussion in this article.

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# American Science between 1780 and 1830

## The exploration and industrialization of the new nation led to advances in natural science and technology.


D. J. Struik


When, in 1783, the United States had emerged victoriously from the ordeals of the Revolutionary War, liberal-minded men and women on both sides of the ocean held high hopes that the new freedom would bring a flowering of the arts and sciences. Fair Columbia, whose Fathers were sages such as Franklin and Washington, had indeed many leaders who had given proof of their concern with the cultivation of knowledge for the betterment of man. The men around the already well-established American Philosophical Society in Philadelphia, soon the capital—Jefferson, Rush, Rittenhouse, and Bartram, not to speak of Franklin—and the men around the new American Academy of Arts and Sciences in Boston—Adams, Cutler, and Bowdoin—had, even during the war, continued to cultivate the sciences. In all the towns along the Atlantic coast were serious gentlemen of scientific inclination, often connected with the colleges in Cambridge, New Haven, New York, Philadelphia, and Williamsburg.


The author is on the staff of the mathematics department of Massachusetts Institute of Technology, Cambridge. This article is based on the author's address to AAAS-Section E (geology), in a symposium on the history of geology, at the AAAS meeting in Washington, D.C., 27 December 1958.


### Growth from Colonialism

These great hopes were bound to be frustrated, at any rate during the early years of the republic. The primary task of any country emerging from colonialism is to catch up with the advanced part of the world, and the United States had many men only too willing to work for this goal. The main efforts had to be economic and political: improvements in transportation and in industry, as well as the raising of the political position of the country among the nations of the world. These tasks, once undertaken, were successfully carried out despite great handicaps: canals were dug, turnpikes were laid out, factories were built, mass production was inaugurated, steamboats were constructed. The Louisiana Purchase improved the political condition of the country in relation to the French, British, and Spanish empires beyond all expectations, giving the United States, moreover, an entrance into the profitable fur trade. The period which opened with the Lancaster turnpike near Philadelphia and the Middlesex Canal near Boston ended with the extension of the National Road far into the deep Middle West and with the ambitious project of the Erie Canal. Opening with the experiments of John Fitch and Oliver Evans in steam navigation (Fig. 1), it ended with the great successes of Robert Fulton's invention on eastern and midwestern rivers, and even (though these were only tentative) on the ocean. It opened with the feeble experiments of Orr, Cabot, and others in textile machinery and ended in the fulfillment of Samuel Slater and Francis Cabot Lowell's experimentation in the factory towns of New England, and even in the foundation of whole new cities, such as that show place, Lowell. It opened with a few merchant ships setting out from Salem, Boston, and other harbors to China and the northwest Pacific and ended with the American merchant marine all over the globe. This progress, begun rather slowly during the early federalist days, gained impetus with the expansion of the popular forces in the days of Jefferson, Madison and Monroe.

This was progress indeed, even though we must be careful in our use of this

word. There was an advancement in science and technique, carried out by a triumphant democracy. It helped many a man to establish a comfortable life and opened untold opportunities for native craftsmen and for immigrants from politically and economically depressed areas of Europe. However, we must not forget that at the same time Eli Whitney's invention of the cotton gin reestablished slavery in the South, that Slater and Lowell's introduction of the factory system created a badly exploited working class, and that the opening of the West spelled lasting doom for the Indians. It was progress for many, but not for all.

The spread of scientific knowledge in its stricter, academic sense at the beginning of this period was much slower than the increase in technology. In those federalist days science was, to a considerable extent, only a continuation of the old mercantilist science of classifying nature, together with some mathematical astronomy and surveying—the one in the spirit of Linnaeus, the other in that of Newton. The stress was on the utilitarian—on the improvement of man's health, of his crop, of his garden, and of his purse, and hence also on his understanding of God's benevolence. But even in those days there were good botanists —William Bartram, Humphrey Marshall, Benjamin Smith Barton in Philadelphia, Gotthilf Mühlenberg in Lancaster, the Michaux at Charleston, and Manasseh Cutler near Boston. Benjamin Waterhouse, in 1788, began to give a college course in botany at Brown and at Harvard; other courses followed, given by Barton in Philadelphia and Mitchill in New York. The American Philosophical Society published *Transactions,* the American Academy in Boston published *Memoirs,* and the versatile Samuel Latham Mitchill in New York began to publish, in 1797, his *Medical Repository,* which included papers in the new sciences of mineralogy, geology, and chemistry.

Chemistry received a great impetus when, in 1794, Joseph Priestley came from witch-hunting England and settled in Northumberland. Several textbooks were published, but on a modest scale; only one book appeared which, in ever-new editions, has became a classic in its kind, the *New Practical Navigator* of Nathaniel Bowditch (1802).

Events of great scientific importance did occur in the America of the last decades of the 18th century, but they took place outside of the republic. The British, masters in Canada after 1763, pursued the age-old search for the Northwest Passage with renewed vigor, driven by the ever-extending hunt for furs. In 1793 Alexander Mackenzie, fur trader and geographer, who in 1789 had followed the "Mackenzie" system of rivers to the Arctic, reached the Pacific Ocean by traveling west from Chippewayan and crossing the Rockies. The trail was new, but the goal was a territory already visited by Russians, Spaniards, and Englishmen; when Mackenzie reached the coast, James Cook's former lieutenant, George Vancouver, was making his excellent topographical surveys nearby. The Yankees had also come; Captain Robert Gray of Boston, on his ship the *Columbia,* had just found the mouth of the great legendary river, the Oregon, and baptized it with the patriotic name of his ship. The great international search for furs in the Northwest was now really on. Men well remembered on the Canadian side are Simon Frazer and David Thompson—the latter, one of the

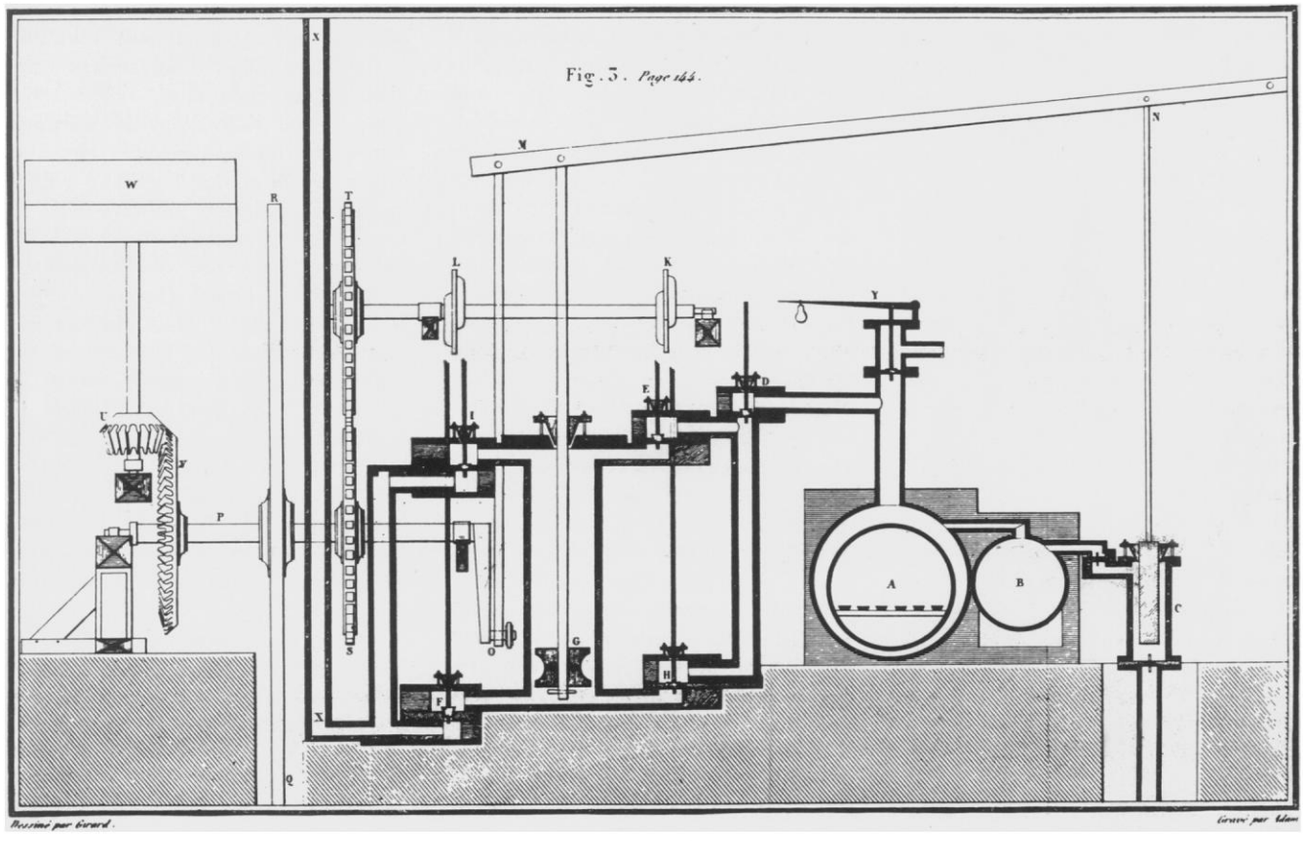


Fig. 1. Vertical section of the "drop-valve engine" (a steam engine of the "high pressure" type) proposed by Oliver Evans in "The abortion of the Young Steam Engineer's Guide" of 1805. Evans, by 1802–03, had a steam engine installed in his flour mill in Delaware. Such engines were small; the engine shown has a boiler about 16 inches in diameter. Evans continued improving his engines until his death in 1819. [From "The abortion of the Young Steam Engineer's Guide," French translation, Paris, 1821]

greatest scientific geographers of America. The famous Lewis and Clark expedition, organized by the United States Government, was also directly related to the highly competitive enterprise of seeking the otter, the seal, and the beaver (*1*).

## Great Explorations

A new period begins in 1801 with the administration of Thomas Jefferson. Science received new life in the wake of the popular movement. The President was himself a man of the widest interest in science and the author of the *Notes on Virginia,* and he became the symbol of the new democracy and the new awakening in science. His thoughts had often centered on the overland routes to the Pacific, with their problems of geography and the possibilities they offered for increase in knowledge of nature and for expansion of the fur trade, combined with their political importance in the face of the surrounding colonial empires of France, Spain, and England. The Louisiana purchase of 1803 found the President prepared. In 1804 William Clark and Merriweather Lewis set out for the Pacific under the auspices of the Federal Government; in two years they explored a large section of the West, along the Missouri through the Rockies to the mouth of the Columbia, and made at last the nature of the Rockies south of the Mackenzie route known to the world at large.

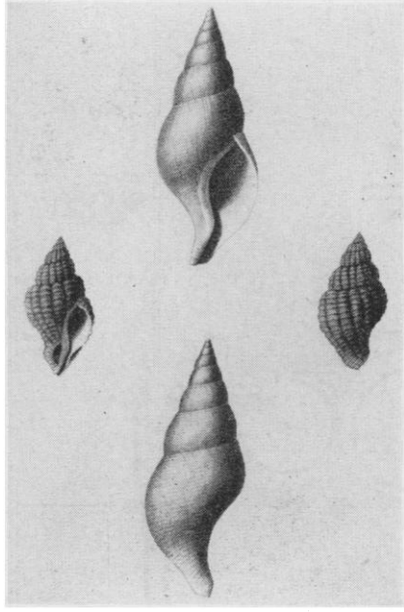

Fig. 2. Shells, drawn for Thomas Say's *American Conchology* [six issues (1830–1834); 60 plates] by Say's wife. The books were published in New Harmony, Ind. (Top and bottom) *Fusus corneus,* from the coast of New Jersey; (center) *F. cinereus,* from the same neighborhood.

At the same time Zebulon Montgomery Pike, commissioned by the Army, led two expeditions, one up the Mississippi to its supposed source in Leech Lake and one along the Platte and Arkansas rivers into the Rockies south of the Lewis and Clark region, where Pike's Peak carries the name of the young officer. Although, because of the embargo and the war with England, there were no more government expeditions until 1818, exploration of the West was undertaken by the newly chartered fur companies, among them Jacob Astor's company, which founded Astoria. Among the many results of the expeditions of these fur traders I mention only Robert Stuart's discovery of the South Pass (1812), which was to open the Oregon trail. In the meantime scouts also ventured to the southwest into Spanish territories and developed the Santa Fe trail, which became a veritable lifeline of trade after Mexico became an independent republic in 1821.

The Federal Government resumed the sponsorship of scientific expeditions when John Calhoun, in 1817, became Secretary of War in the Monroe administration. Stephen Long, between 1818 and 1819, was sent out twice, once up the Mississippi—in a steamboat—and once into the so-called "Great American Desert" as far as the Rockies, where Longs Peak bears his name. This time some scientifically trained men went with him; among them was Thomas Say of Philadelphia—botanist, entomologist, and conchologist (Fig. 2). In 1820 came the expedition led by Lewis Cass, governor of Michigan territory, which went by Lake Superior to the source of the Mississippi, now located at Cass Lake, beyond Leech (*2*). With Cass went Henry Schoolcraft as geologist and anthropologist and David Bates Douglass of West Point as topographer and botanist (Fig. 3). The reports of these expeditions were printed and widely read. The idea of government-sponsored research into the natural resources of the country now became accepted in wider circles, if only for direct utilitarian reasons (*3*).

It was not only traders, trappers, and government officials who ventured into the wilderness, and the wilderness, in those days, was not only the Great American Desert or the Rockies but well-nigh all territory more than, at most, a hundred miles away from the eastern cities.

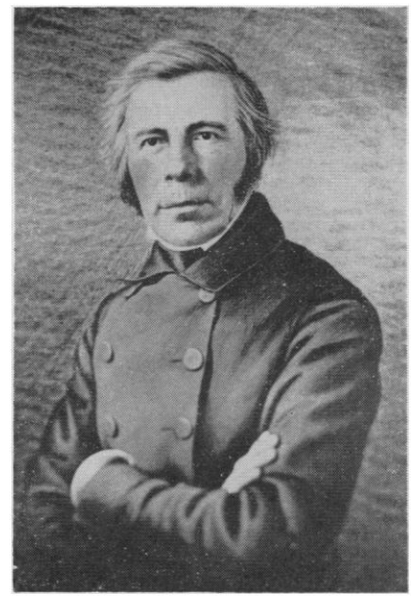

Fig. 3. Picture of David Bates Douglass (1790–1849), reproduced with kind permission from a portrait belonging to the family. Douglass, a Yale graduate, soldier, surveyor, teacher, botanist, architect, and canal builder, was a typical scientist-engineer of his time. He participated in the Cass expedition of 1820.

There were also privately sponsored scientific expeditions, and naturalists even entered alone into the forests and prairies to find plants, animals, and minerals. They followed an ancient tradition, set by such men as Hernandez, Catesby and Kalm, and the Bartrams, but where these older men had been either sent or commissioned by a European principal, the initiative now became more and more American. The Michaux, *père et fils,* were still commissioned by the French Government, and it is also true that William Maclure, who paid many of the bills of wandering scientists, was a Scotsman who had made his money in London, but Maclure did his own exploring and during his long stay in the United States identified himself with the country. From 1812 until his death in 1840 he was president of the Academy of Natural Sciences at Philadelphia, of which he was a founder.

Among the naturalists who went out, often for many months, sometimes on expeditions with others, sometimes quite alone, we find many of the great figures of early American science: the two Michaux, Alexander Wilson, William Maclure, Thomas Say, Constantin Rafinesque, Thomas Nuttall, Edwin James, James Audubon, Charles Lesueur, Titian Peale, and Henry Schoolcraft. While all had the true naturalist's universal, scien-

tific love of nature, they had their fields of specialization; Wilson (Fig. 4), Say, Nuttall, and Audubon specialized in birds, Maclure and Schoolcraft in geology, Rafinesque and Nuttall in plants, Lesueur in fishes, and Say in shells, while Lesueur and Peale made lovely sketches and drawings. I cannot here give an account of all their travels, from Florida to Vermont, from the Alleghenies to the Rockies, nor can I enumerate the many publications which came from their pens, some of which—for example, Maclure's *Observations on the Geology of the U.S.* (1809, 1817), Say's *American Entomology* (1824–1827), or Wilson's *American Ornithology* (1808–1813)—are classics in their field. In these men, those who like to trace "parenthood" in various fields of science have a wealth of subjects: Maclure is the father of American geology; Wilson, of American ornithology; and Say, of American entomology; to these names can be added those of Caspar Wistar of the University of Pennsylvania, father of American surgery, and Lewis von Schweinitz, father of the study of Cryptogamia.

This, truly, was the heroic age of American nature study. These scientific explorers braved for months on end the hardships of the wilderness, of prairie, forest, river, and mountain, the danger of hostile Indians, and the exasperating nuisance of insects, to bring back whole collections of stones, plants, animals, and artifacts. They were all most remarkable men, headstrong, with marked peculiarities which might even make them the butt of popular witticisms on posy-seekers and bug-hunters. The beginning of Dickens' *Pickwick Papers* reflects this attitude; an American counterpart is Dr. Obed Battius in Fenimore Cooper's *Prairie,* said to be a take-off of Thomas Nuttall. Many were liberal in their political outlook and confessed, with Mitchill of New York, that they "supported the republican party because Mr. Jefferson was its leader, and supported Mr. Jefferson because he was a philosopher." This explains why several of them showed enthusiasm for Robert Owen's socialistic and Maclure's pedagogic experiment at New Harmony, Indiana, on the Wabash. In the winter of 1825–1826, Say, Lesueur, and the Dutch geologist Gerard Troost joined the "Boat load of Knowledge" which sailed down the Ohio from Pittsburgh and landed at New Harmony. Though the colony failed as an experiment in social reform, New Harmony was and remained for many years a rendezvous in the wilderness for many naturalists.

## Academicians

These naturalists in the field were supported by a number of outstanding scientists in the colleges. The number of such colleges was increasing considerably, though the teaching of the natural sciences and of advanced mathematics was only slowly introduced, even at the leading schools. Chemistry had come to the United States with Priestley, who found men willing to listen to him—men such as James Woodhouse in Philadelphia, John Maclean at Princeton, and Mitchill in New York—even though they did not follow the master in his phlogiston theory. At the same time, with Priestley, came Thomas Cooper, who would for many years stir the South with his freethinking and his passion for scientific education.

The first native chemist whose research received wide attention was Robert Hare of Philadelphia, whose studies of the composition of water led him to the invention of a new kind of blowpipe for generating high temperatures. However, it was Benjamin Silliman, who gave his first lectures as a professor at Yale in 1804, who became America's best known chemist, not only by virtue of his research and his popular lectures but

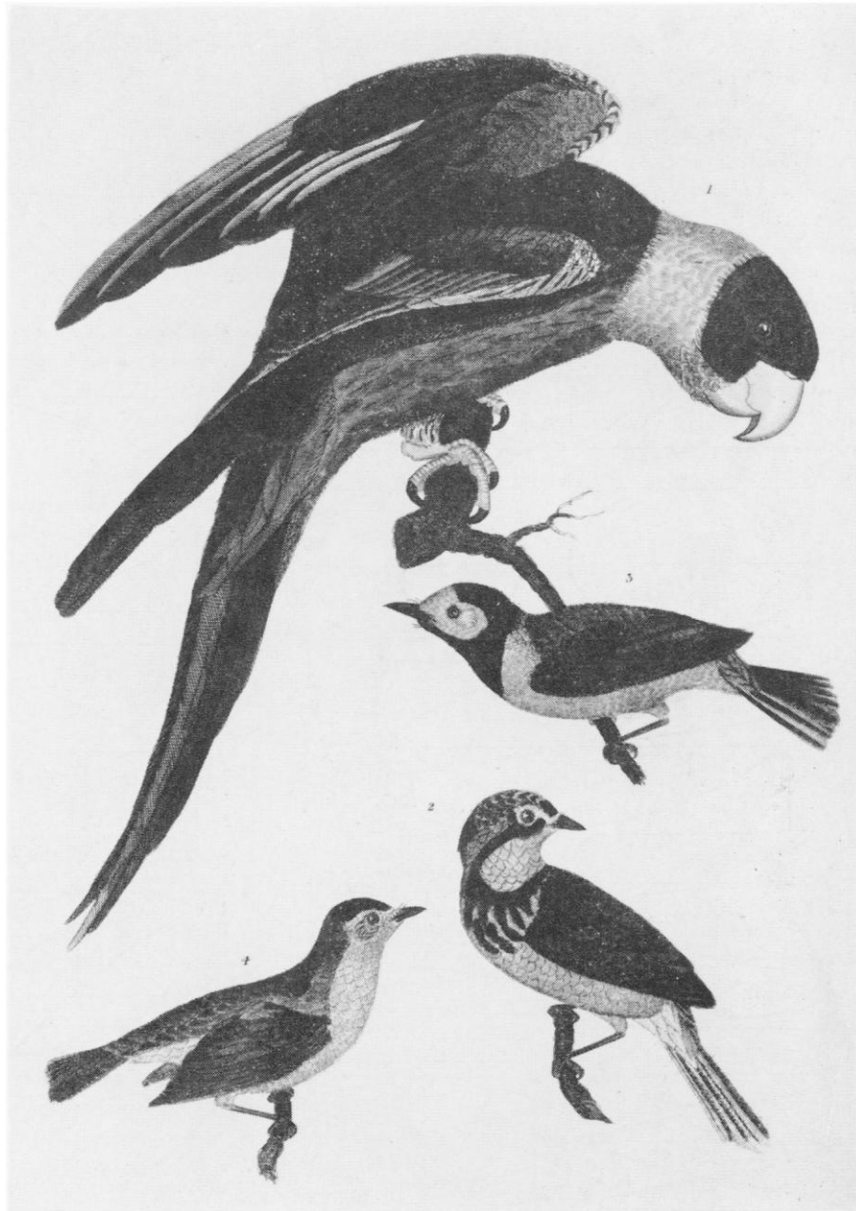

Fig. 4. The Carolina parrot (now probably extinct) by Alexander Wilson. Spoiled as we are by Audubon's paintings, our appreciation of Wilson's bird pictures is not always what it should be. This may have been a picture of a living bird, since Wilson had one with him on his wanderings from Big Bone Lick, in Kentucky, to New Orleans, in 1810 (*4*). The other birds are flycatchers.

also as the founder and editor of the *American Journal of Science,* which still exists. It soon became the central organ for all naturalists in the United States.

Silliman, like Mitchill, was also a mineralogist and a geologist. Scientists in this field were a novelty in the United States. Maclure, as I have mentioned, had published a first comprehensive monograph on the geology of the United States in 1809, the result of much traveling. Many monographs followed, including local surveys by Mitchill in New York, by Silliman in New Haven, and by the Danas in Boston, as well as Schoolcraft's descriptions of the lead mines near Dubuque (1818) and the copper deposits of Lake Superior (1821). The first comprehensive text on mineralogy and geology was written by Parker Cleaveland of Bowdoin College (1816, 1822), which was long a standard text. In the 'twenties began that systematic surveying (first, through private initiative) of whole states which led to the great geological surveys of the 'thirties. The first of these surveys was the Deni-

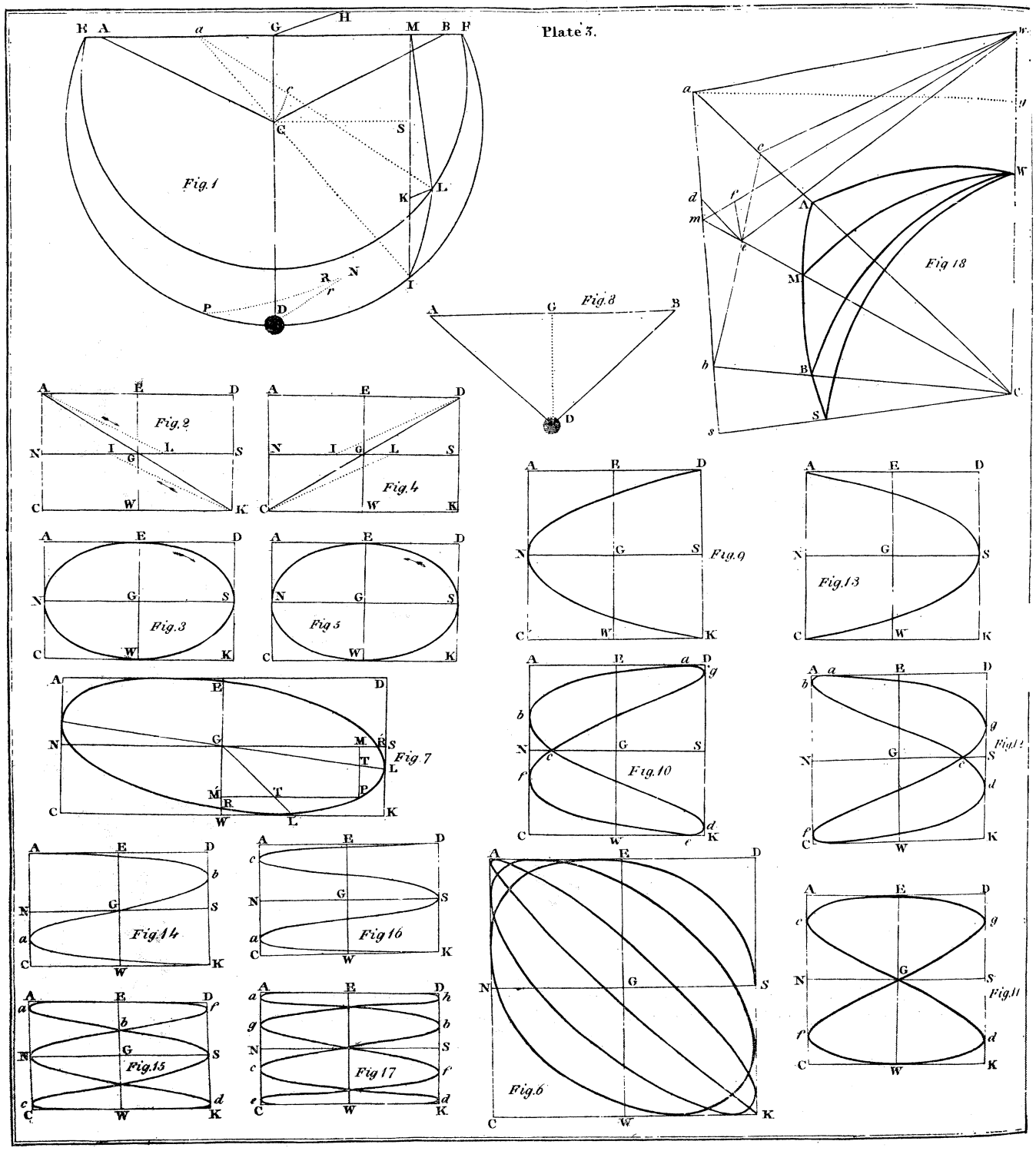


Fig. 5. Figures, known as Lissajous figures, developed by Nathaniel Bowditch (*5*) from his studies of the motion of a pendulum suspended from two points, through the application of Laplace's methods, as explained in the latter's *Mécanique célèste.* This is one of the earliest American contributions to theoretical mechanics.

son Olmsted survey of North Carolina in 1823 (made with state authorization); this was followed by the survey of Nova Scotia by Francis Alger and Charles Thomas Jackson in 1828.

Botany and zoology also advanced rapidly, in considerable part through study of the collections brought home by the surveying expeditions. The botanical collections of the Lewis and Clark expedition were analyzed by Frederick Pursh, a gardener of German stock who worked in several private botanical gardens in Philadelphia and New York; he published his results in London in his *American Flora* of 1813. The botanical collections of Long's expedition were analyzed by John Torrey of New York (1828); it was at this period that Torrey also worked on his description of all plants of the United States—an ambitious project started by Barton in 1803. Just as Cleaveland's work was followed by that of James Dwight Dana and Wilson's work by that of Audubon, so was Torrey's work followed by that of Asa Gray.

A word must be said about the remarkable scientific work done in some of the frontier towns. We think of New Harmony; of Gerard Troost in Nashville, after his farewell to New Harmony; of Daniel Drake in Cincinnati; and of Rafinesque at Transylvania University in Lexington, Kentucky. Among the most famous scientific frontier achievements was the series of experiments of William Beaumont on gastric juices, which began at the Mackinac Army post in the heart of the Indian country.

## Exact Sciences

When we compare the gallant efforts of the naturalists, the successes of the chemists, botanists, and geologists, and the inventiveness of the canal and steamboat builders with the accomplishments of the mathematicians and physicists during this period, we are aware of an anticlimax. In the gradual emergence from a colonial economy, the sciences closest to the temper of the country enjoyed the greatest interest. Conditions in a republic of self-conscious citizens were different from those under a European monarchy where the more subtle arts could flourish under royal patronage. Even in electricity, where research was initiated with such success in Franklin's day, little advance was made before Joseph Henry, in the 'thirties, responded to the European discoveries of his day as Franklin had responded in his time. The pages of the *American Journal of Science,* though open to all the sciences and even to the arts, were singularly barren of papers on the exact sciences.

With Benjamin Thompson moping abroad as Count Rumford until his death in 1813, the only well-known representative of the physical and mathematical sciences of those days was Nathaniel Bowditch, pillar of the Boston Academy, the practical navigator whose translation of Laplace's *Mécanique célèste* began to appear in 1829 (Fig. 5). Among other mathematicians of this period was Robert Adrain, born in Ireland, who taught at several colleges in the East and edited the first purely mathematical journals in this country. Modernization of mathematical instruction came with John Farrar at Harvard, who translated several French texts. West Point, under Sylvanus Thayer, was headed in the same direction. Also from West Point came our first academically trained engineers. Rensselaer followed, founded in 1826, the oldest polytechnic institute in the country. The few medical schools were in many respects pioneers in the teaching of scientific subjects, not only in materia medica but also in chemistry and other natural sciences. It was Benjamin Waterhouse, of the Harvard Medical School, who in 1800 introduced cowpox vaccination into the United States. I have already mentioned other teachers at medical schools: Mitchill in New York, Wistar in Philadelphia.

The U.S. Coast Survey was founded in 1807, a foster child of Jefferson's. It was 1816 before the survey started work, under the leadership of Ferdinand Ru-

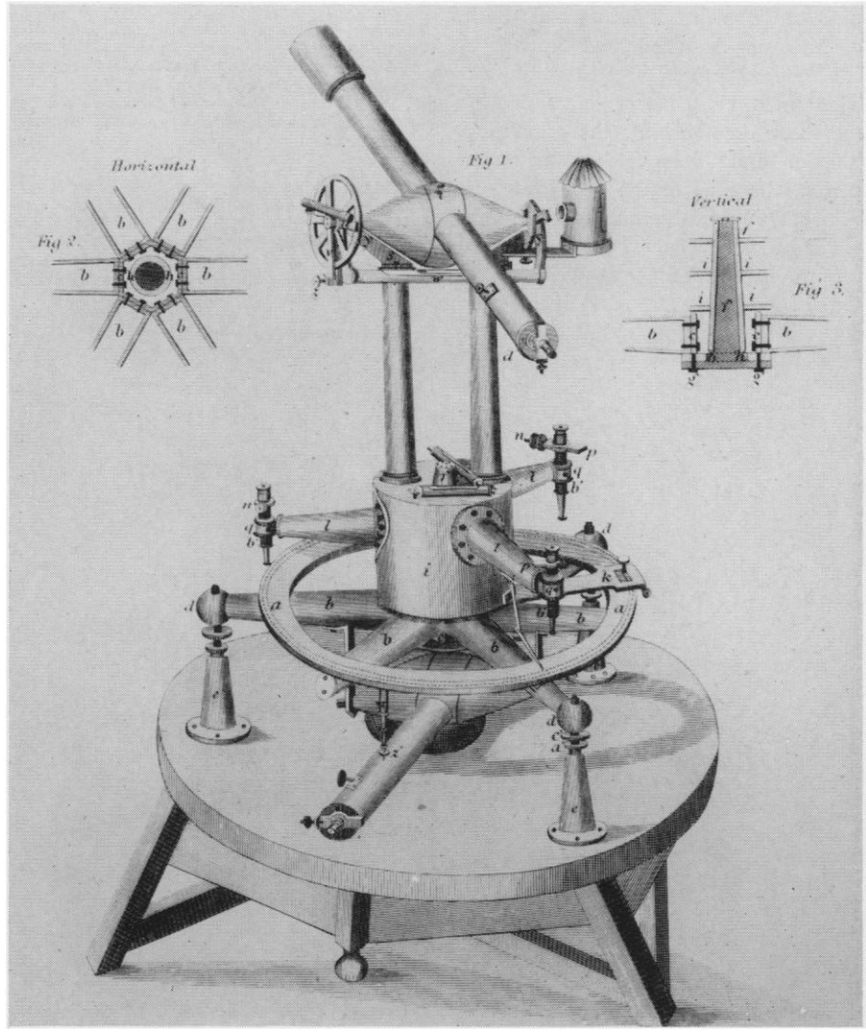


Fig. 6. Theodolite used by Ferdinand Hassler for his early work on the U.S. Coast Survey (*6*). It was constructed by the famous Edward Troughton of London. Its horizontal circle (*aa*) was 2 feet in diameter and was mounted by three compound microscopes of 1:14 enlargement. The telescope, of 2½-inch aperture, had four magnifying powers, the largest being 1:77.

dolph Hassler, a Swiss mathematician and surveyor, whose insistence on the highest possible accuracy of measurement set standards which have ever guided the survey, now called the U.S. Coast and Geodetic Survey (Fig. 6). After issuing some charts it discontinued its activities until 1832. The same lack of interest which characterized the Congress in matters of geodetic surveying can be seen in the frustration of attempts by Joel Barlow and others to found a national university and of John Quincy Adams to found a national observatory. His proposed "light houses in the sky" even became a butt for the wits of those days.

Perhaps I should not leave the subject on this note of anticlimax and should redirect attention to the pioneer naturalists and inventors of those days. We must first of all remember the period as the time of the great explorations and of the great start in industrialization—the time of Jefferson, of Lewis and Clark, of Maclure, Audubon, and Nuttall, of Eli Whitney, and of Robert Fulton. These men laid a lasting foundation for the future—notably for the astonishing 'thirties and 'forties, the Jacksonian period, the time of the geological surveys, the time of the railroads and other technological advances, the time of the professional scientists, as well as the time of the great causes and of the great debates.

### References and Notes

1. Another important event was Alexander von Humboldt's expedition to the Orinoco and Andes regions, which ended in Mexico and in Humboldt's return to Europe in 1804, via Philadelphia and Washington, where he met many learned Americans, including President Jefferson.
2. David Thompson had done better in 1798, when he located the source of the Mississippi in Turtle Lake beyond Cass; see Thompson's narrative of his explorations in Western America, 1784–1812, J. B. Tyrrell, ed. (Toronto, Canada, 1916).
3. To this period also belongs the Russian expedition under Ferdinand Wrangel which, between 1820 and 1824, carefully studied the Siberian coast from the mouth of the Indigirka to Kolyuchin Bay and thus finally established that there is no land connection between Asia and America. Another Russian expedition under Fabian G. von Bellingshausen made geographical discoveries in the antarctic between 1819 and 1821. Here it met with Yankee sealers, among them Nathaniel Brown Palmer, the discoverer of Palmer (Graham) Land (1820).
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# Geology, Geologists, and the AAAS

## The inclusive association has an important role to play in a time of increasing specialization in science.


Kirtley F. Mather


Herman L. Fairchild, in his history of the American Association for the Advancement of Science (*1*) recorded the fact that on an old residence in Albany, New York, there was a bronze tablet bearing an inscription which told of the organization of the Association of American Geologists, the "parent body" (Fig. 1).

The decade of the 1830's was marked by an extraordinary burgeoning of interest in the newly developing science of geology in eastern North America. Water power was proving inadequate for the rapidly expanding industries. Exploitation of the coal of the Appalachian coal fields was moving ahead with increasing momentum. Mineral resources in great variety were insistently demanded to meet the needs for raw materials in the many new manufacturing plants. The survey of the four "Geological Districts of the State of New York" was getting well under way. The office of state geologist was inaugurated in Massachusetts and Virginia, and before the end of the decade, 17 states had made some sort of provision for geological surveys. Sound bases for geological thinking and for the interpretation of field observations had been established in Great Britain by William "Strata" Smith, Sir Roderick Murchison, Sir Charles Lyell, and others. Such knowledge was infiltrating what was then still the New World. Many professors of natural history or of natural philosophy in 20 or more institutions of higher learning, scattered from New England to Virginia, were concentrating their work upon the