The Neesima Lectures II: The Flourishing of French Science, 1770-1830
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pg. 211

TEN

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In my lecture on American science, I ventured to characterize a dynamic structure of relations between science and the state, between knowledge and power, as one of the features defining modern political systems. I also suggested that it first took on identifiable form during the period of French scientific eminence at the end of the eighteenth century. The appropriate place to begin developing that proposition is with the ministry of Turgot, the statesman and encyclopedist who drew upon science and systematic knowledge in formulating policies intended to rehabilitate the French monarchy on the accession of Louis XVI in 1774. During the next half-century, say between the last years of d'Alembert and the death of Laplace in 1827, the French scientific establishment predominated in the world to a degree that no other national complex has since done or had ever done.

Its eminence persisted through the lifetime of two generations rather well marked off one from the other. The earlier was that of Lavoisier, Laplace, and Monge in their most creative years, of Lagrange in his maturity, of Coulomb, Buffon and the young Lamarck, to name a few of the more famous—in a word, of the final generation of the old Royal Academy of Science, founded in the seventeenth century along with the Royal Society of London. Their successors were the first generation of the Institut de France and the École Polytechnique, still the two senior technical bodies in France; I mention here a few names that appear in all our current textbooks—Ampère, Dulong, Petit, Fresnel, Fourier, Poisson, Cuvier, Bichat, Sadi Carnot, Cauchy.

There was a contrast in spirit between those two generations. The outlook of the former was encyclopedist and pertained to the eighteenth cen-

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tury and to the Enlightenment. The outlook of the latter was positivist and pertained to engineering and to the nineteenth century. The succession in generations corresponds to large-scale political phases. The earlier extended from 1774, the beginning of attempts at reform, through the opening of the Revolution in 1789, down to the overthrow of the monarchy late in 1792. The Reign of Terror that ensued in 1793 and 1794 was something of a hiatus in science, though certainly not in politics. The second phase, like the careers of our second group, extended from the reorganization following the overthrow of Robespierre in mid-1794 through the Napoleonic period and the Restoration down to the July Revolution of 1830.

In the work of this half-century of science, I believe that French cultural leadership in Europe reached its zenith. I mean that statement very broadly. The critical movement of classicism that distinguished the French intellectual spirit first made itself fully felt in the reign of Louis XIV in the seventeenth century, and in the realm of letters, architecture and manners. Thereafter it took the form of the system of rational ideas about nature, humanity, and society called the Enlightenment. Passing over from thought to action, that movement issued in the incorporation of science into polity amid the circumstances that are the subject of this lecture. Throughout, the sectors in which science came to be of moment to the state were broadly those in which its relation with society have transpired generally in modern history. They were three, as we observed in the case of the maturing of American science over a century later: first, administration and public works, civil as well as military; second, education, as to both training and recruitment of élites; third, technology, in respect to industry and agriculture, to engineering and invention.

I shall consider first the sense in which science figured in the measures introduced into administration by Turgot and by his entourage. Like their predecessors, the writers and *philosophes* of the type of Voltaire, Diderot and Rousseau, the enlightened reformers of the last decades of the Old Regime were critical of authority. Unlike literary people, they were critical of it rather in its exercise than in its existence, however, and proposed indeed to avail themselves of the instruments of authority to bring about rational changes. Expert knowledge was their hallmark rather than propaganda and philosophy, and the enemy was rather routine and ignorance than despotism in the abstract.

First, public affairs: perhaps the most striking, though not the most effective, illustration was the application of mathematics to social phenomena and governmental processes themselves. I have discussed this aspect of the subject with students specializing in the history of science at

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Tokyo University, and here I will simply quote Turgot's conviction. It was "that the moral and political sciences are capable of the same certainty as those that comprise the physical sciences, and even as those branches . . . which, like astronomy, seem to approach mathematical certainty." Condorcet was Turgot's principal man of confidence in the Academy of Science. In service to his patron's belief, Condorcet began the application of the calculus of probability to analysis of the selection and voting procedures of electoral bodies and of judicial panels. Even more important for the development of the theory of probability itself, Laplace started the statistical analysis of population figures which had been collected systematically in France throughout the eighteenth century, and thus initiated a mathematically based science of demography. Thereupon the taking of a census as a normal act of government followed early in the Napoleonic period.

Of all the reforms stemming from the Revolution, the one that most regularly affects the daily doings of scientists and other men was certainly the creation of the metric system of weights and measures. It is a common mistake, however, to suppose that it began in the early phase of a revolutionary passion for basing social arrangements on uniformities in nature. Like most things in the Revolution, its origins go back to reforms attempted by the Old Regime, and specifically to Turgot's appointment of Condorcet to be Inspector of the Mint. His instructions were to develop a proposal for standardizing and unifying commercial and scientific units of measurement, preferably on a decimal basis. Again like many such improvements, only the impetus of the Revolution invested government with the authority to carry the change into effect. Another misinterpretation, of a more technical nature, concerns the definition of the meter as the ten-millionth part of the quadrant of the meridian. That decision is also often attributed to ideology, or else to the desire of astronomers to secure government funding for an ambitious geodesic survey. The alternative would have been adoption of the more easily determined length of a pendulum with a frequency of sixty oscillations per minute at the 45th parallel. In fact, the preference for the meridional survey had a perfectly good mathematical justification; Laplace was the one responsible for it. Only so could celestial and terrestrial measurements be numerically interchangeable, so that unit angle on the celestial sphere subtended unit length on the earth. Unfortunately, angular measurement is the one sector where decimal subdivision failed to catch on.

Armaments also pertain to public works, and of all Turgot's administrative reforms the most immediately successful was his reorganization of the gunpowder industry. Everywhere in Europe fabrication of powder

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had been a sovereign function, like coinage or justice, since the introduction of explosives from Asia in the fifteenth century. In the late seventeenth century, the scale became so large that the French government began leasing out the facilities to private enterprise. Speculators took over in the eighteenth century. An ancient trade-guild had a monopoly of exercising the royal right of entry to scavenge in private property for saltpetre, the principal ingredient. The saltpetremen preferred living from bribes by owners who paid them not to search, and the financiers, who were supposed to monopolize their product to produce gunpowder below cost, concentrated on speculating with the advances from the crown instead of on manufacturing munitions. The situation was a scandal, therefore, typical of the entire regime of privilege and exemption, and blamed by the military for their loss of the Seven Years War against England from 1756 to 1763.

In correcting it, Turgot turned first to the Academy of Science, and charged it to institute an urgent and exceptional study for chemical production of saltpetre. He dismissed the powder farmers and substituted a commission responsible directly to the Ministry of Finance. More important, he put Lavoisier in charge of the commission. Thus did the science of chemistry and its leading light enter into the sort of relation to the military which is familiar to our times, and to America, from the example of the science of physics and its leaders in the 1940s. One consequence is seldom noticed by historians of science. It is that the chemical revolution, out of which emerged the modern science, occurred in the Arsenal of Paris. Lavoisier's laboratory there was the nerve center, the social center, and the experimental center of French science in the years down to 1792 and his fall from political favor in the political revolution. Lavoisier succeeded brilliantly in restoring the munitions industry to self-sufficiency, with capacity adequate to furnish arms also to the American armies in our revolutionary struggle. It is true that no new theory was involved, and that the triumph was one of responsible and expert administration rather than of science—unless, as I believe, that itself can be called scientific. Moreover, Lavoisier was arrogant and high-handed and made enemies of the suppliers, the working men, and the population in the quarter around the Arsenal. His unpopularity contributed to his arrest and execution by the guillotine at the climax of the Terror in 1794, at the very time when the revolutionary armies were being supplied with ammunition by methods he had devised.

Only as a consequence of institutions created in the French Revolution could education become one of the principal sectors wherein the place of science was important to the state. France had admirable secondary

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schools in the eighteenth century, and many of them taught science well. They were all religious foundations, however, and the one institution providing higher technical education, was the small military engineering school at Mézières. For scientific education in general, all we have in the early phase of the Revolution is a series of projects. They are interesting, however, in showing what the leaders of scientific opinion—Turgot, Lavoisier, Dupont de Nemours—had in mind.

They considered, first, that education at all levels must be taken out of the hands of the church and assumed by agencies of the state. They considered, secondly, that citizenship would pre-suppose an educated population, at least up to the level of universal literacy. They considered, finally, that instruction in science and its applications must replace Latin and the humanities as the staple subject-matter in the formation of responsible and productive citizens. Sensibility must be oriented to change and to shaping the future, and no longer to tradition and conserving the past with its agelong accumulation of abuses. The Academy of Science was itself to be reorganized and enlarged and turned from the fount of honor and supreme tribunal of research into the ultimate authority in education, prescribing the curriculum, writing the textbooks, examining the qualifications of teachers, inspecting the operations of the classroom. That never came about, but that notion of a proper role for science in society tells much about the mentality of the leaders of the reforming generation among French intellectuals.

In the area of technology, to turn to our third sector, science had not yet reached the stage where basic theory was proving immediately applicable to processes of production, as it began to be after the middle of the nineteenth century. Science was related to industry rather in a descriptive and regulatory capacity. Throughout the eighteenth century, the French government called on scientists to undertake studies of industrial processes, not so much with a view to finding new ones, as to determining what were the best ones. Officials had in view bringing French industry abreast of more progressive and productive technologies that had evolved in the free enterprise system of the British economy, and also in Germany and Scandinavia, mainly in metallurgy. The result was a kind of natural history or encyclopedia of industry, of which the prime examples are the great multi-volume *Description of the Arts and Trades* published by the Academy of Science from 1750 through the 1780s, and the technical parts of the Diderot *Encyclopedia* itself. Under government encouragement, scientists produced a literature of manuals bringing into the open processes that had always been handed down as trade secrets—and identifying the best of them.

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More specifically, the government also made of scientists the arbiters of its policy of encouraging and subsidizing inventions. Patents were unknown to French law before the revolution, but the government did make a practice of awarding prizes, subsidies, and sometimes monopolies, for a term of years to inventive entrepreneurs. When an artisan with an invention or a manufacturer with a new process approached the government with the request for a grant, the proposal would be referred to a committee appointed by the Academy of Science. It was their duty to pass upon its originality and merit. Many members of the Academy themselves had direct technological responsibilities in government regulatory agencies and state enterprises. In effect, the Academy of Science was thus the highest technological authority in the state, and the exercise of its responsibility inevitably created resentments. The great majority of so-called inventions were chimerical and valueless. In keeping with the haughtiness and disdainfulness that often characterized class relations in the Old Regime, scientists developed the reputation among artisans for arrogance, pride, unfairness, and even exploitation of the ideas of practical men. Those resentments were politically the most powerful aspect of the hostility to the Academy of Science that manifested itself as the revolution moved to the left, and the champions of the sansculottes, or working classes, gained power.

At the same time, a current of intellectual and emotional hostility to exact and abstract science emerged among certain writers, politicians, and demagogues in the early 1790s. That attitude, as a kind of unformulated, deeply felt anti-thesis to scientific rationalism, goes far back into the cultural history of the eighteenth century. Rousseau was its greatest exemplar. The attitude exhibits a psychology of alienation from the structure of modern society that is always latent, in my judgment. It emerges, or becomes influential, in times when authority is called into question, and is then often associated with radical political movements, whether of left or right. Other examples are the world-wide anti-scientism of the 1970s and the anti-rationalism that was so prominent a feature of German culture in the Weimar Period before the rise of Hitler. It is a further feature of these mentalities that they couple rejection of authoritative, abstract, mathematical or mechanistic science based in physics with enthusiasm for what they imagine to be an alternative science based in biology and in romantic sympathies between man and nature.

The contest between these conflicting attitudes, and the empathy between the latter and political radicalism, makes sense out of what the historian of science would otherwise find to be a very puzzling paradox in the French Revolution. For, in the summer of 1793, as power came into the

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hands of the Jacobin left and the dictatorial Committee of Public Safety, the enemies that the Academy of Science had made in its domination of technical affairs carried the day. On 8 August 1793 the Academy of Science was declared to be a body whose existence was incompatible with a republic, and it was abolished, along with other privileged academies. Those who had exercised leadership since the time of Turgot—Lavoisier, Cassini, Condorcet, Bailly, Laplace, Vicq d'Azyr—went into prison, and some to the guillotine, or into hiding. But at virtually the same time, the Convention, which had thus dismissed the guardians of rigor in exact science, lavished favor on the institution responsible for the biological sciences. The old Royal Botanical Garden—the famous *Jardin des Plantes*—was democratized and confided to the responsibility of its own staff, and twelve professorships of natural history, botany, anatomy, geology, paleontology, and so on were created. Twelve chairs: there was no scientific institution in the world in the 1790s with so munificent a provision of professorships. In the contrasting fate of institutions, the reality of radical hostility to exact science and enthusiasm for life science is perfectly evident.

Equally interesting is the conduct of the scientific community when under attack. In no way did it react like a political faction. There was no opposition from science to the regime that had proscribed its corporate existence. Indeed, throughout the entire period that concerns us, from the Turgot Ministry to the July Revolution of 1830, the political behavior of scientists makes striking contrast with that of other groups among the intelligentsia, such as artists, writers, philosophers, and social scientists. The scientists pressed into the service of each regime, without regard to political or constitutional distinctions, and from each they drew a measure of advantage for science. The French Revolution was the crucible in which modern politics was formed, and not only for France. For that reason the behavior of the scientific community, the most developed in the world, is the paradigm case of what I have called the relation of partnership rather than partisanship that obtains between science and government, whatever the momentary strife of party or of principle.

France was at war from the spring of 1792. The suppression of the Academy of Science coincided with extreme military urgency in the summer of 1793. Far from rallying to their fallen leaders, remaining members of the Academy rallied to the war effort in the autumn, winter and spring of 1793–1794—the year II in the revolutionary calendar. They took the lead in devising and overseeing methods for emergency production of saltpetre, gunpowder, firearms, cannon, and clothing for the armies. It would be an exaggeration to attribute French victories to the con-

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tributions of science, but the scientific commission on armaments that served under the governing Committee of Public Safety certainly marks the entry of science into the military service of the modern nation in arms. It will convey the spirit of the effort if I quote from the account Cuvier left in the official éloge of Berthollet, the leading chemist in France after the arrest of Lavoisier:

> Everyone recalls that prodigious and sudden effort which astounded all Europe, and aroused admiration even among the enemy it thwarted. Monsieur Berthollet and M. Monge were the moving spirits. It was according to their instructions that this immense movement was directed. The chemists who were commissioned to conduct tests for so many new procedures worked only by their instructions; and it is said that, if they had wished to follow up all the secrets they came upon, weapons more powerful than any we possess would have emerged from their laboratories.
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> It would be wrong to suppose that the use of such inventions is at last accounts as harmful to humanity as their effects are alarming. Exactly the contrary is the case. It is not only that science, in furnishing civilized peoples with these means of defense, has been the sturdiest shield of civilization itself;
>
> Nor is it merely that science has been able to count on the support of government only since it became one of the essential elements of the art of war.
>
> But, paradoxical though the assertion may appear it would be easy to prove that the means of destruction furnished by science, in rendering combat more decisive, have made wars less frequent and less murderous.
>
> As for M. Berthollet, what he primarily saw in these extraordinary developments of human industry, motivated by the greatest of interests were simply chemical experiments on a large scale.

Not for nothing was science thus involved in the events that changed the world. Traversing them consummated its own transformation into the professional enterprise that it has been ever since, and that it fully became in the careers of the second, the Napoleonic generation of French scientific leadership. Political reaction following the liquidation of the Jacobin regime in July 1794—the 9th of Thermidor in the revolutionary calendar—never lessened the enthusiasm with which the scientific community served the state. Napoleon was following Jacobin precedent when, the youthful general on the rise, he named a small staff of scientists to ac-

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company him in the invasion of Italy in 1796. Monge, Berthollet, and Geoffroy Saint-Hilaire were the principle parties, their mission being to appropriate whatever of scientific and artistic value might serve the republic. Such was the satisfaction that Napoleon took in their company in the respites of the campaign, that he conceived the far more elaborate notion of attaching an entire scientific and archaeological expedition to his task force when he set forth on the conquest of Egypt in 1798. The camp-following of sixty men of science and learning that he there organized into the Institute of Cairo founded the science of Egyptology. Monge and Berthollet were the leaders once again, but they were getting to be elders. The younger men, notably Fourier, Geoffroy, and Savigny, had the exciting experience of a summons to participate in a great affair at the impressionable beginning of their careers. The entire adventure presaged the resonance that scientific eminence would lend to the Napoleonic regime in later years.

In speaking of professionalization, we are concerned with the second scientific revolution, as historians call the transformation that came over science in the first decade of the nineteenth century. It had to do both with the content and the organization of the various disciplines. It will exhibit what happened if we compare the classification of knowledge as it appeared in the *Encyclopédie* of Diderot and d'Alembert in the 1750s to that of Auguste Comte, the founder of the positive philosophy, who was educated at École Polytechnique from 1817. D'Alembert divides physical science into mathematical science and general plus experimental physics. The former consists of rational mechanics with a little astronomy and optics. Problems of sound, electricity, magnetism, heat, chemistry—all that belonged only to experimental physics whereas the life sciences and earth sciences pertained to natural history except for the medical parts of anatomy and physiology.

Auguste Comte, on the other hand, elaborating his philosophy out of the very practice of the first generation of the nineteenth century, conceived the order of the sciences to be that which every schoolboy now supposes to be simply natural: mathematics, astronomy, physics, chemistry, biology, and sociology. It is important to note that the d'Alembert classification was reflected in the organization of the old Academy of Science, and the positivist in that of the body that replaced it in the reorganization of science after the Terror, the Institute of France.

What had brought the change? To a very considerable degree, of course, factors internal to the sciences, in the obvious sense that experimental knowledge and mathematical analysis had developed to the point that the mathematical physics of Poisson, of Fresnel, of Fourier, of Ampère

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was in fact possible. The same might be said for biology, considering the analysis of zoological information by the techniques of comparative anatomy and of the creation of experimental physiology in the new practice of clinical medicine in teaching hospitals. It is virtually a law of the evolution of science that its direction has been toward more sophisticated and extensive modes of quantification, and at any stage the qualitative is outranked or superseded by the quantitative.

In a sense, the statements I have just made beg the question, however, since what we wish to know is what had changed the circumstances of men who can now properly be called professional scientists to bring about those developments just there, just then, and in that way. It is as anachronistic to speak of professional science in the eighteenth century as it is of mathematical physics, and perhaps it would be well to be definite about what we mean by professional. A profession, I take it, is distinguished by three attributes. First, it is an association more definite than an occupation, in that its practice presupposes mastery of a body of knowledge, and thereby qualifies for the prestige attaching to the cognitive. In the second place, however, a profession does share the economic character of an occupation. It is legitimately followed for gain and is not a status held of right, even though terms like fees or honoraria are preferred to words like wages or profits. Finally, and most distinctively, a profession is self-governing, in that it exercises jurisdiction over the education, qualifications, and conduct of its members, usually by tacit or actual delegation from the state, supposedly in accordance with the public interest.

If this definition of professional is acceptable, it follows that the word when applied to vocations prior to the French Revolution must still be reserved for divinity, law and medicine. Science did not yet qualify. It was coming close, closer than the humanities or social sciences, and much closer than pedagogy, engineering, or the military. But the French community of science, though more advanced than any other under the Old Regime, could fully satisfy only the first of these criteria, the possession of natural knowledge. As for the second, livelihood, scientific breadwinning was an unsystematic affair. For the most part, members of the old Academy did hold positions of some sort involving technical knowledge and supporting a modest style. But if they were not sinecures, and some were, they generally entailed purposes other than research and engaged the scientist's ability only obliquely to his investigations and well behind their frontier—school-teaching, examining military cadets, pharmacy, consulting on porcelains or dyes, and so on.

Turning to the third sector, self-governance, the Academy did exercise a large and adequate measure of control over its own membership, though

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botanists might yet have a voice in the selection of chemists. But it was in the field of education that the situation remained almost wholly unprofessional before the Revolution and before the foundation of the École Polytechnique and the École Normale in 1794 and 1795. That occurred in the immediate aftermath of the Terror and amid the continuing pressures of the war. The École Normale was conceived in too generous a fit of enthusiasm at first. Intended to train teachers for a nation full of schools, it tried gathering some 1400 pupils into the auditoriums of the *Jardin des Plantes,* and they ranged from virtual illiteracy to the virtuosity of the young Fourier.

The École Polytechnique, on the other hand, was a success from the very outset. Conceived by Monge, Prieur and Carnot, Polytechnique was intended to open to general competition the opportunity for the kind of education formerly given to the military engineers at Mézières, though on a larger scale and carried to a far more advanced level. The school long bore the marks of its origin. Its regime was paramilitary. The numbers were significant but manageable—392 students at the outset.

They were chosen by competitive examination. The course required three years of intensive application. For the first time in the history of science, students were being put through a systematic scientific and mathematical curriculum under the foremost scientific minds: Lagrange on the theory of analytical functions; Laplace on the theory of probability; Monge himself on descriptive geometry; Fourcroy, Berthollet and after him Gay-Lussac on modern chemistry. The students were able and eager. They lived their days at Polytechnique exhilarated by the sense of being conducted to the very forefront of scientific conquest, and being told that the future of mankind, of the Republic, and not least of themselves depended on how they performed in so exposed a situation. The mood was messianic, and this was the spirit turned into philosophy by Comte, for whom science would know only in order to predict and predict only in order to control. Indeed, positivism in scientific thinking was a proper creation of the Revolution, not of this or that faction or party, but of its consciousness and action, whether directed left or right. It was the philosophy of that thrust which Revolution and Empire made in common, the philosophy of that science which would fulfill itself in engineering—civil engineering, social engineering, perhaps the engineering of humanity itself.

Yet when they graduated, Biot, Malus, Fourier, and the rest, they did physics. (So, too, did those formed in the courses of the regenerated *Jardin des Plantes* and the schools of health do biology. The story there is congruent, if less dramatic.) To see how it was that these, the modern scientific disciplines, emerged out of this crucible, we must look to the combi-

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nation of the new pedagogical and educational modes with the older tradition of encyclopaedic rationalism revived and redirected in the Institute of France—a living encyclopaedia, its founders called it. A revival of the academies in republican form, the Institute carried over into the new order the responsibility of an enlightened state for science, arts and letters. The difference in the dispositions reflects what had happened in the cultural scale of values. There was as yet no replacement for the literary rule of the *Académie Française.* The Institute consisted of three "classes," science coming first in precedence and numbers with sixty resident members, moral and political science second with thirty-six, and fine arts and literature third with forty-eight. Each class was subdivided into sections according to a modern definition of the disciplines: mathematics, mechanics, astronomy, etc. The first class resumed the functions of the Academy, serving science as the goal of young ambition and the guardian of standards, and the state as high court of technical resort. Laplace and Cuvier became the lawgivers in their respective spheres, and for Laplace the creation of a mathematical physics was no mere function of the logic of development of his subject: it was a matter of conscious policy, to be elicited from the young men, to be favored in the publication of this memoir and not that, in the award of prizes or places to this person and not the other.

These, the sociological and institutional factors in the professionalization of science, may be specified quite explicitly, I think, and they lead me to feel some confidence in a final remark that I'll make bold to venture. It has to do with the intangibles, the qualities of pride and collective self-confidence that distinguish the professional man from the retainer, who lives from patronage and serves a master. The founders of Polytechnique and its first generation of students saw themselves in a heroic guise, continuing at a high level of mathematical sophistication the enlistment of science in the service of the republic that had begun in the Levée-en-masse and the revolutionary production of weapons, material and even strategy in the extremity of the year II. That sense of having played a worthy part in the great events of the time—it made men of them, and not merely professional men.

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