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THEODORE STRONG AND ANTE-BELLUM AMERICAN MATHEMATICS

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SUMMARIES

Theodore Strong was a prolific contributor to the mathematical and scientific journals of ante-bellum America. His work was not remarkable in its originality, but it dealt with mathematics that was quite sophisticated for its time and place. Strong's published work was a significant factor in the dissemination of advanced mathematics to his countrymen, and he played an important role in the education of a few mathematicians who were active in the latter part of the 19th century, most notably George William Hill.

Theodore Strong a été un prolifique collaborateur des revues mathématiques et scientifiques de l'Amérique d'avant la Guerre Civile. Ce n'est pas leur originalité qui rend ses travaux remarquables mais plutôt leur niveau mathématique élevé pour cette époque aux Etats-Unis. Ses publications jouèrent un rôle important dans la diffusion, auprès de ses compatriotes, des mathématiques supérieures. Quelques mathématiciens, actifs à la fin du siècle, le plus connu étant George William Hill, doivent en partie leur formation à Strong.

INTRODUCTION

Theodore Strong (1790-1869) was an American mathematician who was active in the first half of the 19th century [1]. His accomplishments do not match those of his two better-known contemporaries, Nathaniel Bowditch and Robert Adrain, but Strong was important in introducing Continental mathematics into the United States and was extremely active mathematically, as is evidenced by the Bibliography of Strong's Work accompanying this paper. (See also [Struik 1976, 103; Bradley 1886, 25].)

Strong won wide recognition as one of the leading American scientists of his day; and, during the brief time between the end of Bowditch's and Adrain's productivity and the beginning of

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Benjamin Peirce's, Strong is reasonably described as the foremost mathematician in the United States. He was elected to the American Academy of Arts and Sciences in 1832 and to the American Philosophical Society in 1844, and became one of the original members of the National Academy of Sciences in 1863.

Strong received his college education at Yale, where he graduated in 1812, winning the prize in mathematics [Bradley 1886, 4; Dwight 1871, 362]. After leaving Yale he became the mathematics tutor at Hamilton College in Clinton, New York, and subsequently became the college's first professor of mathematics. While at Hamilton, Strong declined offers from Queen's College (Rutgers), Columbia University, and the University of Pennsylvania before finally accepting a second offer from Rutgers College in 1827. He remained at Rutgers College until his retirement in 1863 [Bradley 1886, 14].

During Strong's lifetime significant progress was made in the quality and quantity of mathematical work done in the United States, and most of these significant mathematical developments are reflected in his work. Thus, despite the fact that Strong was not the most outstanding mathematician of ante-bellum America, a study of his life affords many insights into the mathematics of this period.

Striking evidence of the progress of American mathematics during Strong's lifetime is found in a comparison of Strong's mathematics professor, Jeremiah Day, and his most important student, George William Hill. Typical of professors in ante-bellum American colleges, Day did not carry out any significant research; whereas his student, Hill, was one of the first outstanding research scientists born in the United States.

In making this comparison, it is easy to lose sight of the fact that considering the time and place Strong received a remarkably good scientific and mathematical education at Yale. The somewhat inflexible classical curriculum of the day prevented concentrated study in a particular science, and there were no opportunities to do graduate work in the United States at this time. However, Strong benefited not only from studying under Day, but from Benjamin Silliman as well. Silliman was one of the first Americans who endeavored to promote professional science in the United States. He founded the *American Journal of Science*, also known as *Silliman's Journal*. (On Silliman see [Reingold 1964; Guralnick 1975, 209-210].)

Benjamin Silliman is justly credited as one of the founders of American science; however, Jeremiah Day, who was also a theologian and president of Yale, has received an undeservedly bad reputation as an educational reactionary, owing to his coauthoring the Yale report of 1828 [Day & Kingsley 1828] while he was President of Yale. This document has generally been viewed as a negative, but highly potent, force in American higher education. Day has been stereotyped as the champion of the classical, totally prescribed liberal arts curriculum, which dominated the ante-bellum American college. He has also been viewed as the enemy of both vocational and scientific education [2].

But Day made an extremely important, and often overlooked, contribution to the development of American mathematics [3]: he was the first American to write mathematics textbooks [Day 1811, 1814, 1815, 1817] the subject matter of which was substantially beyond arithmetic [4]. This accomplishment was substantial; Florian Cajori observed that these books fulfilled America's then most important mathematical need [Cajori 1890, 63-64]. Good textbooks were needed to educate good mathematicians, but the texts used in the United States up to that time stressed the memorization of long and complex sets of rules, which were often given without adequate examples. Furthermore Day's books exhibit the first important influence of French mathematics on American mathematical education [Cajori 1890, 63-64; Simons 1931]. Day gave Legendre's *Geometry* and Lacroix's *Algebra* as references in his texts and cited several of Euler's works. Day's texts are also closer to the French than to the English texts in style and approach.

Clearly written and pedagogically sound, Day's texts enjoyed extensive use. His *Algebra*, in particular, met with immense success and underwent more consecutively numbered editions than any other American mathematical work before 1850. Only Dabold's and Dilworth's arithmetics went through as many editions [Karpinski 1940, 202].

Although Day did not do serious or extensive research, he did publish several papers on astronomy [Day 1813a, b; Day & Kingsley 1813], which he wrote before he became President of Yale. Thus, although not a research mathematician, Day was certainly mathematically competent and was among the top American mathematics professors of his time.

In contrast to Day, however, is Strong's best-known student, George William Hill. George William Hill (1838-1914) and Simon Newcomb (1835-1909) were the first Americans to do important research in mathematical astronomy. Hill did work in nearly every branch of celestial mechanics, his work in lunar theory being especially important. He did pioneering work in the theory of homogeneous linear differential equations and the use of infinite determinants. Hill was one of the first Americans to enjoy an international reputation as a quantitative scientist and was probably better appreciated in Europe than in his native country. When he was introduced to Poincaré during the latter's visit to the United States, Poincaré's first words were, "You are the one man I came to America to see" [Woodward 1914; Moulton 1914; Brown 1915; Eisele 1972, 398-400; Smith & Ginsburg 1934, 129-131].

Thus Strong emerges as a visible link between the mathematicians of Colonial and Federal America--the non-research-oriented college professors and gentleman philomaths--and the research mathematicians who began to appear at the end of the 19th century.

STRONG'S CONTRIBUTIONS TO MATHEMATICAL EDUCATION

Unlike Day and a string of textbook writers and translators who followed him--including John Farrar of Harvard, Charles Davies of West Point, and, later, Elias Loomis of Yale--Strong made no significant contribution as an author of texts. His *Treatise on elementary and higher algebra* [1859] was published in his sixty-ninth year. Although the book met with sympathetic reviews, it sold poorly, and all but a few copies were destroyed [Bradley 1886, 15-16]. The text is an amalgam of elementary material and some of Strong's most sophisticated mathematical work, most of which had been published previously in periodicals. The text is too advanced to be suitable for a novice; yet most of the book covers elementary material that would be of little interest to anyone with sufficient mathematical knowledge to read the few more advanced sections [Bradley 1886, 15-16]. Strong's only other text [1869], a treatise on calculus, was written in the summer of 1867 and published posthumously, in the year after Strong's death [Dwight 1871, 362-363]. Apparently this text enjoyed no wider circulation than the *Algebra*; and I have not been able to locate a copy for study.

At best Strong's contributions as a college teacher appear to be equivocal. To his few students who had substantial mathematical talent, he was certainly able to offer far more than most of his contemporaries. However, as with other ante-bellum college professors, few of Strong's students became notable mathematicians. The only one, in addition to Hill, of whom I am aware is George W. Coakley, who graduated from Rutgers in 1836 and subsequently became a mathematics professor [Demarest 1924, 286]. There were others who appreciated Strong's teaching, even though they did not become professional mathematicians. Joseph P. Bradley, a student of Strong's at Rutgers and later an Associate Justice of the United States Supreme Court, stated that the philanthropist and social reformer, Gerrit Smith, and the philologist and geographer, Edward Robinson, both found Strong an inspiring teacher. These few men of significant talent were probably the exception, however. From his own experience, Bradley conceded that Strong was a poor teacher for most students, often digressing into a discussion of mathematics wholly unintelligible to his pupils. His contemporary R. Adrain was guilty of similar digressions; but Strong, unlike Adrain, had a reputation for being patient and congenial in the classroom [Bradley 1886, 12]. (On Adrain see [Hogan 1977; Coolidge 1926].)

Since Hill was Strong's most outstanding student, the nature of Strong's influence on Hill is especially important in assessing Strong's contribution as a teacher. R. S. Woodward observed that Hill's

> *early education appears to have been without noteworthy incident until he entered Rutgers College, where he attained the degree of A.B. in 1859, and where he had the good fortune to be introduced while yet an undergraduate to the* Mécanique Céleste *of Laplace. This introduction was furnished by Dr. Theodore Strong ..., then professor of mathematics and natural philosophy in Rutgers College, and one of the small number of Americans devoted to mathematico-physical science at that time. Strong had a good library in this science to which his pupil was given free access, and Hill often referred in terms of grateful appreciation to this circumstance as one of the determining factors in his remarkable career of research in dynamical astronomy.* [Woodward 1914, 161]

Hill wrote:

> *Having shown some aptitude in mathematics, it was decided to send me to college; and, in October, 1855, I took up residence at Rutgers College, New Brunswick, N.J. Here I found Dr. Theodore Strong, professor of mathematics, who was a friend of Dr. Nathaniel Bowditch, the translator of Laplace's* Mécanique Céleste. *I remember seeing in Dr. Strong's library, the presentation copy of this work. Under his guidance, I read such books as Lacroix,* Traité du Calcul Différential et intégral; *Poisson,* Traité de Mécanique; *Pontecoulant,* Théorie Analytique de Systeme du Monde; *Laplace,* Mécanique Céleste; *Lagrange,* Mécanique Analytique; *Legendre,* Fonctions Elliptiques. *My professor was an old fashioned man; he liked to go back to Leonard Euler for all his theorems; as he said, "Euler is our Great master." He scarcely had a book in his library published later than 1840.* [Woodward 1914, 161]

Hill's description of Strong's library indicates that while Strong did acquaint himself with Laplace and Lagrange, he was not familiar with the works of later mathematicians such as Gauss and Cauchy. This was typical of even the best American mathematicians of the first third to the first half of the 19th century, including Adrain and Bowditch. They embraced 18thcentury Continental mathematics, but ignored the Continental mathematics of the next century. The first Americans to study Continental mathematics of the 19th century were the succeeding generation of American mathematicians, which included Benjamin Peirce, George William Hill, Simon Newcomb, Josiah Willard Gibbs, Charles S. Peirce, and others.

STRONG'S MATHEMATICAL WORK

Besides making a significant contribution to the education of George William Hill and those sufficiently talented students who could appreciate him as a teacher, Strong made an important contribution to the growth of American mathematics through his prolific publications in the contemporary mathematical and scientific journals.

Unlike Jeremiah Day, Strong made a serious attempt to do mathematical research, even though he did not produce any significant work--certainly nothing that would compare with that done by men who followed him, like Hill and Benjamin Peirce. Jeremiah Day described the difference between his and Strong's work in a letter to Strong written in December of 1813.

> *I am very glad to see you placed in a situation where you have opportunity for investigation in your favorite science. I wish I had myself more leisure to devote to the higher departments of science. But as I am now situated I can do little more than endeavor to render truths long since discovered intelligible to those whom I am bound to instruct.* (Quoted by Bradley [1886, 6])

As noted above, even though Day was not a research mathematician, he did have much to offer Strong as a student. And although the influence of Silliman and, perhaps, other sources should not be discounted, Day's influence upon Strong was obviously considerable and, from the existing evidence, greater than that of Silliman. Strong corresponded with both men after he left Yale, but his one existing letter to Silliman is largely confined to details of the publication of one of Strong's articles and to personal pleasantries. In contrast, he continued to correspond with Day about his work at least 6 years after the latter became President of Yale in 1817. Early in his career Strong wrote to Day:

> *Since I know you to be a lover of truth and scientific investigation and as I have good reason to believe that you are friendly to me I will with your permission sub-*

> *mit to your examination whatever propositions I may have the ability to discover or to demonstrate in a different manner from what others have done (provided they are of any importance). I will accordingly communicate to you at this time some properties of the circle which are new to me and which I have succeeded in demonstrating* [5].

Strong's first mathematical work [1814], to which he referred in the above letter, reflects his classical education at Yale and the heavy influence of British mathematics upon American mathematics at that time. This work was a set of proofs of theorems on the circle that were first posed by Mathew Stewart in 1814. Stewart had served as professor at the University of Edinburgh from 1747 to 1772, where he collaborated with his mentor, Robert Simpson, in restoring Euclid's books on porisms and did other work in synthetic Euclidean geometry [Sneddon 1976, 54-55]. In 1746 Stewart published without proof the theorems Strong later proved. Demonstrations, differing from the later ones of Strong, were given in 1805 by James Glenie in a paper published in the *Philosophical Transactions of the Royal Society of Edinburgh* [Glenie 1812]. Strong noted, in the introduction to his article on the circle, that he had become acquainted with Stewart's problems through the article on the "Circle" which had been published in Abraham Rees' *Cyclopaedia*. This article does note Glenie's proofs and cites where they were published. But Strong may have merely received a transcription of the problems and not seen the article. Strong stated in a letter to Day dated August 26, 1816 [6], that he had not yet seen Glenie's proofs, but he did not mention if he knew that the problems had already been solved when he worked on his own solutions.

After publishing three additional papers [1818-1819a, 1818-1819b, 1820] which dealt, in turn, with synthetic Euclidean geometry, trigonometry, and number theory, Strong came under an influence that was both considerable and beneficent to American mathematics: that of French and other Continental mathematics. Indeed, Strong made an important contribution to the growth of American mathematics by being one of the leaders in introducing Continental mathematics to his countrymen. Whether or not Day had earlier introduced Strong to the works of Continental authors is unknown, but Strong's work during the years immediately following his graduation from Yale certainly did not show any Continental influence.

The first evidence of Strong's contact with Continental mathematics is in a letter written to Jeremiah Day in 1816. Strong wrote that he had lately received:

> *100 volumes of mathematical and astronomical books from Europe. Among which are Vince's work on astronomy, DelLambre's ditto, Laplace on probabilities, Arbogast on derivations, Lacroix on the differential Calculus, group researches, Legendre on C. elliptic transcendentals, Cognoli on trigonometry, Lagrange on Mechanics, Woodhouse's principles of analytic calculation* [6].

After receiving this library, Strong eventually began to publish work which revealed a marked Continental, especially French, influence. He first displayed this influence by using Leibnitz' notation in a solution to a problem in the *Mathematical Diary* [1825-1832 1, 34]. This problem appeared in the second issue of the Journal, which had commenced quarterly publication in 1825 under the editorship of Robert Adrain, and which was principally devoted to problem solving. Hence, the problem appeared either in 1825 or 1826. (The copy of the journal to which I have access gives a date for only the first issue.)

During the first quarter of the 19th century, there was very little mathematical work, even of an elementary nature, done in the United States that dealt with Continental mathematics and its notation. Leibnitz' notation was completely absent from Adrain's *Analyst* (1808-1809) and the Journal displayed few influences by Continental mathematicians; previous American work showed almost none. There was very little mathematical work published in periodicals between the time when Adrain's *Analyst* ceased publication, and the time when the first issue of *Mathematical Diary (1825-1832)* appeared [Karpinski 1940, 581-591]. Two notable exceptions that did use Leibnitz' notation for the calculus were [Schubert 1818] and [Fisher 1822]. The only book published in the United States prior to 1826 in which Leibnitz' notation appeared was John Farrar's translation of Etienne Bezout's *First principles of the differential and integral calculus* [Karpinski 1940, 256]. (Nathaniel Bowditch did not publish the first volume of his *Mécanique céleste* until 1829.) A partiality for Newton's notation and concepts persisted among American mathematicians even after the Continental works began to appear in the United States. Even Robert Adrain expressed his preference for fluxions in the first issue of the *Mathematical Diary*, and many contributors to the *Mathematical Diary* continued to use the Newtonian notation well into the 19th century.

The problem cited above was the first of many that Strong proposed and/or solved in the *Mathematical Diary* which exhibited a Continental influence. Of particular interest is Strong's solution, in the third issue of the Journal, of the "prize" problem that had been proposed by Robert Adrain:

> *It is required to investigate the path that ought to be described by a boat in crossing a river given breadth from a given point on one side, to a given point on the other, so as to make the passage in the least time possible; supposing the simple velocity of the current being in the same direction with the parallel sides of the river, is variable and expressed by any given function of the perpendicular distance from that side of the river from which the boat sets out.* [*Mathematical Diary* 1825-1832 1, No. 2, 48]

Again using Leibnitz' notation, Strong solved this problem with the calculus of variations.

In an article entitled "Solution of a problem in fluxions" [1829], Strong investigated the path of a moving particle acted upon by various forces. This was the first of a series of articles by Strong on mechanics (emphasizing celestial mechanics) which appeared in the *American Journal of Science.* These articles were published over a period of more than a decade [Strong 1829; 1830a; 1831-1833; 1834a, b; 1835; 1836a, b; 1842b].

This series of papers also used Leibnitz' notation and was strongly influenced by Laplace and Lagrange. Indeed these papers are little more than commentaries on Laplace's *Mécanique céleste* and Lagrange's *Mécanique analytique*. The articles were important in helping to make these works known and appreciated in Strong's native country. They undoubtedly had a much wider circulation than Nathaniel Bowditch' translation of Laplace' *Mécanique céleste*. And they would likely be more conducive to actual study, since their serialized form was less formidable than Bowditch' massive volumes.

Although there was a rather abrupt shift in Strong's work from synthetic geometry to French mechanics, one also sees a continual, if more subtle, shift away from British sources to the more modern mathematics of the French and Continental authors. For example, even though Strong discussed Laplace and Lagrange in the entire series of articles referred to above, he cited Vince' *Fluxions* as a source for many of the theorems he used in the earlier articles in this series. However, in the later articles he began to use Lacroix's *Calculus* as a basic reference.

Strong published work in virtually every branch of mathematics that was pursued in the United States during his productive life. He maintained a lifelong interest in geometry, but did progressively more work in analytic, rather than synthetic, geometry. In addition to posing and solving problems in mechanics, calculus, and number theory, Strong published papers dealing with infinite series and products, and the theory of equations [e.g., 1836-1839 1, 293; 376; 2, 41; 1842-1843, 158].

While Strong's work shows considerable facility for mathematical manipulation and originality of method, it almost always consists of the reworking of previously obtained results. Strong summarized the value and, I think, the intent of most of his work in this rather typical comment appearing in one of his articles in the *American Journal of Science*:

> ... *this value of v is the same that Laplace has found at page 181, vol. I. of the Mécanique Céleste, and if I am not greatly deceived the method which I have used is altogether more simple and easy than his.* [1831, 73]

Much of Strong's work was typified by reasonably sophisticated mathematical manipulation. His proof of the Binomial Theorem [1827] and his paper on exponential and logarithmic theorems [1845] fall into this category. Typical of this area of Strong's work is a solution to the irreducible case of the cubic equation, which appeared in Strong's *Algebra*. It is probably the piece of work that Strong's contemporaries considered his most notable accomplishment [Colton 1869, 27; Dwight 1871, 362; Bradley 1886, 17].

To derive Cardan's formulas for the cubic equation, the general cubic is transformed, by means of a substitution, to an equation of the form

$$x^3 + ax = b. \tag{1}$$

A further substitution, $x = t - a/3t$, and multiplication by t^3 transform (1) into

$$t^6 - bt^3 - a^3/27 = 0. \tag{2}$$

which is a quadratic equation in t^3. a and b are real numbers, and the discriminant of (2) is $b^2 + 4a^3/27$. If the discriminant is negative, (1) will have only real roots. However, the solutions obtained using Cardan's formulas will express these real solutions in terms of the cube roots of complex numbers. Furthermore, attempting to obtain the cube roots of these complex numbers by simple algebraic methods reduces to solving the initial equation, (1). This case (when the discriminant is negative) is called the *irreducible case*, and the traditional way of handling it is to extract the cube roots of the complex numbers trigonometrically [Uspensky 1948, 84-93].

Strong offered the following algebraic solution for this case. Since $a < 0$ whenever the discriminant is negative, Strong substituted $-a$ for a in (1), obtaining

$$x^3 - ax = b, \tag{3}$$

where $a > 0$, b is real, and $b^2/a^3 \leq 4/27$. Strong defined v by setting

$$x = 3b/a(3v - 1). \tag{4}$$

Then $v^3 - v/3 = b^2/a^3 - 2/27$, which, when $b^2/a^3 = 4/27$, becomes $v^3 - v/3 - 2/27 = 0$, or $(v - 2/3)(v + 1/3)^2 = 0$, from which x can be obtained easily.

Next, Strong set $N = \sqrt{27b^2/a^3}$, and, noting that $N < 2$, he observed that the sequence of numbers

$$N, \quad \sqrt{N+2}\,, \quad \sqrt{\sqrt{N+2} + 2}\,, \quad \sqrt{\sqrt{\sqrt{N+2} + 2} + 2}\,, \ldots$$

approaches 2. (Since $b^2/a^3 \leq 4/27$, $N \leq 2$ and $N > 0$.)

Using an iterative process, Strong introduced V, V', V'', ... as follows

$$V^3 - V/3 = N/27 \quad \text{and} \quad V = N/3(3v-1)$$
$$V'^3 - V'/3 = \sqrt{N+2}/27 \quad \text{and} \quad V' = \sqrt{N+2}/3(3v-1) \tag{5}$$
$$V''^3 - V''/3 = \sqrt{\sqrt{N+2} + 2}/27 \quad \text{and} \quad V'' = \sqrt{\sqrt{(N+2)} + 2}/3(3v-1)$$

and so forth, until the expression

$$\sqrt{\sqrt{\sqrt{N+2} + 2} + 2}$$

is as close to 2 as required by the number of decimal places specified in the solution. Then setting $V^{(n)} = 2/3$, Strong substituted this value, reiteratively, into the series of equations (5), thereby obtaining a root. That is, he used the value of 2/3 for $V^{(n)}$ to solve for $V^{(n-1)}$; then using this value of $V^{(n-1)}$, he found $V^{(n-2)}$, etc., until he found the value of v, from which he obtained x using Eq. (4). Finally, the remaining two roots were obtained as solutions of a quadratic equation.

This algorithm shows a respectable level of mathematical ingenuity and sophistication, but it is of little practical or theoretical value. Horner, in 1819, had already published the well-known algorithm, which bears his name, for solving polynomial equations of any degree. His method is both more efficient than Strong's method and of far wider applicability. Since all of the reviewers of Strong's *Algebra* were acquainted with Horner's method, it is very unlikely that Strong was not [7].

Although Strong received considerable recognition, he had few contemporaries in the United States who were his mathematical peers, and he must have been frustrated by the very small number of Americans who could appreciate his accomplishments. The mathematical journals to which he contributed were poorly supported and usually short-lived. Silliman's *Journal* (*The American Journal of Science*), in which Strong published many papers, was not a journal for men with highly specialized scientific training, but for the liberally educated gentleman with scientific interests [Schmidt 1957, 52]. Since mathematics is less amenable to popular, descriptive articles than many of the other sciences, articles in mathematics were not among the most suitable for such a publication. Strong wrote to Silliman: "I do not know but I trouble you too much with my speculations; perhaps the *Journal* will succeed better without than with them, for I know very well that people generally are not very fond of mathematics" [8].

Even though Strong's work was inferior to that of both Adrain and Bowditch, it was certainly far superior to most of the mathematical work published in the United States in the first half of the 19th century. In this respect, Strong must be regarded as an important figure in a nation that was making great progress in its mathematical development. His articles and solved problems were significant in introducing Continental mathematics and notation to his countrymen who had mathematical interests. And his researches, though not remarkable in their originality, were based on sophisticated mathematical knowledge and helped to create a climate that was conducive to mathematical research in the following generation.

NOTE ON SOURCES

I was able to find only a small number of manuscript sources on Strong. The Yale University Libraries possess a few letters from Strong to J. Day and one letter from Strong to B. Silliman. The Library of the American Philosophical Society also has a few manuscript items on Strong. Neither Hamilton College nor Rutgers University has any manuscript material related to Strong.

NOTES

1. Theodore Strong is not to be confused with Nehimiah Strong, Professor of Mathematics and Natural Philosophy at Yale from 1770 to 1781.

2. On the Yale Report see [Hofstadter & Smith 1961 I, 252, 275-281; Schmidt 1957, 55-58; Storr 1953, 29-33; Hofstadter & Hardy 1952, 15-17]. Guralnick [1975, 28-33] gives a positive interpretation of Day and the Yale Report.

3. For example, Smith and Ginsburg [1934, 76-78] and Struik [1976, 103] do not mention Day's accomplishments, but they do cite similar ones of John Farrar and Charles Davies.

4. I am excluding from consideration here such books as [Mansfield 1800], which saw limited use as a text, and books the purpose of which was highly instructional but were little used in the classroom, such as [Bowditch 1802]. Pike [1788] contains a small amount of material on algebra, geometry, and other topics besides arithmetic. Webber [1801] was used in American colleges, but as the text's title implies, it was an anthology and not an original text.

5. (November 15, 1813) Letter from Strong to Day, Beinecke Rare Book and Manuscript Library, Yale University; quoted with permission.

6. (August 26, 1816) Letter from Strong to Day, Beinecke Rare Book and Manuscript Library, Yale University; quoted with permission.

7. Horner's method was originally published in the *Philosophical Transactions of the Royal Society* in 1819 and was republished in the *Ladies Diary* in 1838 and in the *Mathematician* in 1843 [Baron 1972]. Strong had devised his method by 1849 [Bradley 1886, 20] and may not have been aware of Horner's method at that time.

8. (July 30, 1831) Letter from Strong to B. Silliman, Silliman Family Papers, Yale University Library; quoted with permission.

REFERENCES

I have separated the General References from a bibliography of Strong's work, which precedes the General References. With a few obvious exceptions, used to incorporate the large number of problems Strong worked on, this bibliography follows the same format as the General References.

BIBLIOGRAPHY OF STRONG'S WORK

I have used the abbreviation *AJS* for the *American Journal of Science*. Almost all of the items in the *Mathematical Diary* and the *Mathematical Miscellany* are problems or solutions to problems, and I have indicated them only by their initial page numbers. Each entry indicates a separate problem.

Strong also communicated five papers to the *National Academy of Sciences* [Bradley 1886, 23] which were apparently never published.

1814	Demonstrations of Stewart's properties of the circle. *Connecticut Academy of Sciences, Memoirs* 1, 393-411.
1818-1819a	An improved method of obtaining the formula for the sines and cosines of the sum and differences of two arcs. *American Journal of Science* 1, 424-426.
1818-1819b	To find the positive and rational numbers, x, y, and z, such that $x^2 - y$, $x^2 - z$, $y^2 - x$, and $y^2 - z$ may all be squares. *AJS* 1, 426-427.
1820	Mathematical problems, with geometrical constructions and demonstrations. *AJS* 2, 54-54, 266-280.
1825-1832	Work in the *Mathematical Diary* articles: Vol. 2: pp. 263-265, 283-285. Problems proposed: Vol. 1: pp. 72, 100, 136, 183, 266, 316. Vol. 2: p. 40 (two items). Problems solved: Vol. 1: pp. 30, 31, 34, 65 (This is a problem using the calculus of variations of which Strong was very proud and later republished the solution in his calculus book), 84, 88, 118, 122, 151, 161, 170, 199, 232, 283, 287. Vol. 2: pp. 12, 20, 23, 48, 67, 80, 98, 117, 121, 132, 139, 158, 165, 169, 173, 178, 218, 224, 226, 237, 247, (two items), 255.
1827	New demonstration of the binomial theorem. *AJS* 12, 132-136.
1829	Solution of a problem in fluxions. *AJS* 16, 283-287; 17, 69-73, 329-334.
1830a	*Ibid.* 18, 67-70.
1830b	On capillary attraction. *AJS* 18, 70-71.
1831	On central forces. *AJS* 19, 46-49; 20, 65-73, 291-294.
1832	*Ibid.* 21, 66-69; 22, 132-135, 342-345.
1833	Motion of a system of bodies. *AJS* 24, 40-46.
1834a	*Ibid.* 25, 281,-289; 26, 44-53.
1834b	On the parallelogram of forces. *AJS* 26, 304-310.
1835	Of the composition and resolution of forces, and statical equilibrium. *AJS* 28, 85-95.

1836a	Of the parallelogram of forces. *AJS* 29, 346-347.
1836b	Theory and variation of the arbitrary constants in elliptic motion. *AJS* 30, 248-266.
1837	Solution of Diophantiane problems. *AJS* 31, 156-158.
1836-1839	Work in the *Mathematical Miscellany* articles: Vol. 1: pp. 259-260, 329, 401-403, 411-412. Vol. 2: pp. 64-71. Problems proposed: Vol. 1: pp. 111, 112. Problems solved: Vol. 1: 64, 67, 77, 100, 142, 143, 144, 156, 163, 175, 212, 231, 235, 293, 301, 307, 321, 364, 369, 376. Vol. 2: 40, 41, 49, 54, 108, 113.
1842-1843	Work in the *Cambridge Miscellany*: Problems solved: pp. 19, 59, 63, 64, 104, 108, 113, 158, 166.
1842a	Integration of a particular kind of differential equations of the second order. *AJS* 42, 273-280.
1842b	A new demonstration of the principle of virtual velocities. *AJS* 42, pp. 66-69; 43, 77-80.
1843a	Remarks on the first principles of the differential calculus, together with a new investigation of Taylor's theorem. *AJS* 45, 269-275.
1843b	On analytical trigonometry. *Proceedings, American Philosophical Society* 1, 49-50.
1843c	Transformation of the series $S + ax + bx^2 + cx^2$, etc., *Proceedings, American Philosophical Society* 1, 138-140.
1845	A new way of obtaining the exponential and logarithmic theorems. *AJS* 48, 36-46.
1859	*A treatise on elementary and higher algebra.* New York: Pratt, Oakley & Co.
1860	Applications of the binomial theorem to the extraction of the roots of whole numbers. *The Mathematical Monthly* 2, 249-252.
1861	Demonstration of the law of equilibrium in the lever. *The Mathematical Monthly* 3, 283-285.
1869	*A treatise on the differential and integral calculus.* New York.

GENERAL REFERENCES

Baron, M. E. 1972. William George Horner, *Dictionary of Scientific Biography* 6, 510-511.

Bowditch, N. 1802. *The new American practical navigator.* Newburyport, Mass.: Edward M. Blunt.

Bradley, J. P. 1886. Memoir of Theodore Strong. *National Academy of Sciences Biographical Memoirs* 2, 1-28.

Brown, E. W. 1915. George William Hill, 1838-1914. *Bulletin of the American Mathematical Society* 21, 499-511.

Cajori, F. 1890. *The teaching and history of mathematics in the United States*. Washington, D.C.: U.S. Gov. Printing Office.
Colton, A. S. 1869. Theodore Strong. In *Memorial of Theodore Strong, LL.D.* New York: S. W. Green.
Coolidge, J. L. 1926. Robert Adrain, and the beginnings of American mathematics. *American Mathematical Monthly* 33, 61-76.
Day, J. 1811. *A practical application of the principles of geometry to the mensuration of superficies and solids.* New Haven, Conn.: Oliver Stelle.
——— 1813a. Observations on the comet of 1811. *Connecticut Academy of Arts and Sciences, Memoirs* 1, 341-352.
——— 1813b. A view of the theories which have been proposed to explain the origin of meteoric stones. *Connecticut Academy of Arts and Sciences, Memoirs* 1, 163-174.
——— 1814. *An introduction to algebra.* New Haven, Conn.: Howe & DeForest.
——— 1815. *A treatise of plane trigonometry.* New Haven, Conn.: Howe & DeForest. The 4th edition (1835, New Haven, Conn.: Hezikiah Howe & Co.) was used in the preparation of this essay.
——— 1817. *The mathematical principles of navigation and surveying.* New Haven, Conn.: Steele & Gray.
——— & Kingsley, J. L. 1813. Calculation on the longitude of Yale College from the solar eclipse of September 17th, 1811. *Connecticut Academy of Arts and Sciences, Memoirs* 1, 353-361.
——— 1828. *Report of the course of instruction in Yale College; by a Committee of the Corporation and the Academical Faculty*, New Haven. A more accessible source, and the one used in the preparation of this essay, is: Original papers in relation to a course of liberal education. *American Journal of Science and Arts* 15 (1829), 197-351.
Demarest, W. H. S. 1924. *A history of Rutgers College: 1766-1924*. New Brunswick, N.J.: Rutgers College.
Dwight, B. W. 1871. *The history of the descendants of Elder John Strong*, Vol. 1. Albany, N.Y.
Eisele, C. 1972. George William Hill. *Dictionary of Scientific Biography* 6, 398-400.
Fisher, A. M. 1822. On maxima and minima of variable quantities *American Journal of Science* 5, 82-93, 304-326.
Glenie, J. 1812. A geometrical investigation of some curious and interesting properties of the circle, etc. *Transactions of the Royal Society of Edinburgh* 6, 22-47. The paper was first read April 1, 1805.
Guralnick, S. M. 1975. *Science and the ante-bellum American college*. Philadelphia: American Philosophical Society.
Hofstadter, R., & Hardy, C. D. 1952. *The development and scope of higher education in America*. New York: Columbia Univ. Press.

——— & Smith, W. (eds.), 1961. *American higher education, a documentary history,* Vol. 1. Chicago: Univ. of Chicago Press.

Hogan, E. R. 1977. Robert Adrain: American mathematician. *Historia Mathematica* 4, 157-172.

Karpinski, L. C. 1940. *Bibliography of mathematical works printed in America through 1850.* Ann Arbor: Univ. of Michigan Press.

Mansfield, J. 1800. *Essay's, mathematical and physical.* New Haven, Conn.: William W. Morse.

Moulton, F. R. 1914. George William Hill. *Popular Astronomy* 22, 391-400.

Pike, N. 1788. *A new and complete system of arithmetic composed for the citizens of the United States.* Newburyport, Mass.

Rees, A. 1810-1824. *The cyclopaedia; or universal dictionary of arts, sciences, and literature.* Philadelphia: Samuel F. Bradford et al. The article on the circle is in Vol. 8; there are no page numbers. The 41 volumes were published between 1810 and 1824, but individual volumes are not dated.

Reingold, N. (ed). 1964. *Science in nineteenth century America, a documentary history.* New York: Hill & Wang.

Schmidt, G. P. 1957. *The liberal arts college: A chapter in American cultural history.* New Brunswick, N.J.: Rutgers University.

Schubert, F. T. 1818. A new investigation of Kepler's problems. *American Academy of Arts and Sciences, Memoirs* 4, 62-73.

Simons, L. G. 1931. The influence of French mathematics at the end of the eighteenth century upon the teaching of mathematics in American colleges. *Isis* 15, 104-123.

Smith, D. E., & Ginsburg, J. 1934. *A history of mathematics in America before 1900.* Chicago: Open Court.

Sneddon, I. N. 1976. Mathew Stewart. *Dictionary of Scientific Biography* 13, 54-55.

Storr, R. J. 1953. *The beginnings of graduate education in America.* Chicago: Univ. of Chicago Press.

Struik, J. D. 1976. Mathematics in Colonial and early Republican America. In *Men and institutions in American Mathematics,* J. D. Tarwater et al., eds., pp. 99-105. Graduate Studies Texas Tech University. Lubbock: Texas Tech Univ.

Uspensky, J. V. 1948. *Theory of equations.* New York: McGraw-Hill.

Webber, S. 1801. *Mathematics, compiled from the best authors.* Boston: Thomas & Andrews.

Woodword, R. S. 1914. George William Hill. *Astronomical Journal* 28, 161-162.