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THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

THE RELATION OF MATHEMATICS TO ENGINEERING.*

A FEW years ago technical education as we now understand it was unknown in America. We have now in our midst more than 20,000 students preparing themselves distinctively for the engineering profession.

While the technical schools of the country have had a development which for rapidity, strength and importance is little short of marvelous, yet their rise and growth have been profoundly influencing the thought as well as the welfare of the nation. Especially in the domain of mathematics have they had a directing and vivifying influence which is little short of a revolution. Today mathematics wishes no stronger reason for her existence and no stronger call to her cultivation than the fact that she is the unchallenged doorkeeper to the appreciation and mastery of the physical sciences, both in their theory and in their application by the engineer to things useful.

The time is past when mathematics is referred to by the thinkers of the day as being principally a discipline. It is of course true that, rightly pursued, mathematics is a discipline, but it is far more, it is a knowledge, a tool, a power, a civilizer. The day is gone when, on the one hand, the student, Chinese fashion, learns his geometry word for word from cover to cover or memorizes all the propositions of his

* Vice-presidential address before Section D, American Association for the Advancement of Science. St. Louis meeting, December, 1903.

analytic geometry down to the last index and subscript, or, on the other hand, when the devotee of a cult toasts his favorite subject with the words 'Here's to the higher mathematics, may they never be useful.'

To the workaday world the higher ranges of mathematics have been a sealed book; the man who traverses them successfully a magician—a man whose mental occupations awaken mingled feelings of awe and pity, awe that he can soar so high, pity that he wastes his strength in such useless flight. A generation ago the mathematician was joined in hand with the Roman and the Greek, and the three easily persuaded the educational world that they were the divine trio. Without them for a basis there could be nothing but a sham college course. Why it was that these three lines of study held such a commanding and, for the most part, unchallenged position, it is now difficult for us to say. Possibly they gained higher esteem as means of mental discipline because their most ardent votaries so seldom succeeded in making them directly useful except in certain narrow professional lines. Of the men in college courses who studied required mathematics beyond trigonometry very few gained any vital conception of analytic geometry and the calculus. To most collegians the mass of symbols with which they juggled in pursuing these subjects was a distressing nightmare, a matter of jest and to be forgotten with all possible speed.

Our colleges to-day have seen a great light and have reformed their curricula. They now know there is no discipline in the pursuit of mathematics to the man who does not understand its language. Early in his course, if not throughout it, the student is allowed the more rational way of getting his education, by pursuing subjects that he *can* understand. This sensible treatment of educational material has grown up during the development of technical colleges and may be referred in a measure at least to their influence. Certainly great advance in the teaching of mathematics has recently been made, yet very much remains to be done, and the next great forward movement seems to be coming directly from the engineers and the forces they are setting in operation.

The literature on the question of reform in the teaching of mathematics is growing rapidly. In 1901 John Perry, professor of mechanics and mathematics of the Royal College of Science, London, and chairman of the Board of Examiners of the Board of Education in Engineering and Mathematics, produced a profound impression upon the British Association by a paper on 'The Teaching of Mathematics.' His ideas require attention further along. In Germany Nernst and Schoenflies, for example, have met the thought of the hour in their 'Einführing in die Mathematische Behandlung der Naturwissenchaften.' In our own country Perry centers are springing up for the reformation and profound improvement, if not revolution, of mathematical teaching in our secondary schools. In the west the apostle of this movement is Professor E. H. Moore, of Chicago University. One needs only to read his admirable presidential address before the American Mathematical Society in New York almost exactly a year ago to understand the full meaning and extent of the changes sought.

The address will be found in the number of the *Bulletin of the American Mathematical Society* for last May, and it will repay a careful perusal on the part of those of you who have not read it. Professor Moore has been counted as a pure mathematician of the most pronounced type, but into this new movement he has thrown himself with the ardor of one whose whole life had been spent in applying a wide range of mathematical power to the design and construction of the great objects of engineering. If the reformation which has been planned and begun shall go on to completion, the mathematical teaching in the secondary schools of the middle west will have little resemblance ten years hence to the work of to-day.

Arithmetic, algebra, geometry and trigonometry will no longer be set off in 'water-tight compartments,' but will all be demanded in various combinations for the solution of single elementary problems. Squared and polar coordinate paper will represent the facts to the eye in geometrical symbolism and at the same time will give a practical introduction to the fundamental ideas of analytics and the calculus. By pursuing through the four years of secondary school life a carefully selected and properly graded problem course the pupil will review the whole range of elementary mathematical truth and become familiar with it, not only in theory, but also in practice. He will never be asking, 'what use?' But with the enthusiasm which original investigation only can arouse he will find his educational material in the simpler problems of the shop, the store, the farm, the bank, the railroad, the steam-boat, the steam-engine, the electric motor, political economy, geodesy, astronomy, time, space, force and so on through the range of the elementary aspects of the things of daily thought and experience in this complex and highly developed life of ours. Such a change can not be perfected in a day. No inferior or untrained teacher can succeed with it. Elementary work must be in the hands of those who have come into living contact with some of the deep, broad problems of chemistry, of physics and of engineering, demanding for their solution a large acquaintance with the higher ranges of mathematics. In turn colleges and universities which strive to train such teachers must revise their mathematical courses and adjust themselves to these new ideas.

In many of our leading institutions exactly that thing is occurring, stimulated perhaps in the first place by the great demand of technical colleges for mathematicians in sympathy with engineering ideas.

Those who are dealing with freshmen in colleges are asking the question, 'What is the matter with our preparatory schools?' If you wish to see this question strongly formulated and illustrated, read the commencement address of 1903 by President Ira Remsen at Mount Holyoke College.

This is the indictment of the schools, that they use, largely to the exclusion of the thought element, a mass of formal and conventional educational material and thus paralyze thought and make abortive any natural mental growth.

In the grades the clear, keen, accurate thinking of childhood soon disappears and does not usually show itself again until the laboratory or the practical problems of life make it once more dominant. We refer to President Remsen's question only so far as it relates to mathematical training. The technical schools long ago recognized the barren results of primary and secondary mathematical instruction and have been deeply interested in its improvement. Most keenly this loss has come to the engineer who must subject himself to the long, hard discipline necessary in his profession for the successful solution of his original and independent problems. Yet certain people seem to look askance upon the engineer and discover no advancement of science in the design of an entirely new machine to carry out an entirely novel idea. According to their notion, Whitney was not a scientist when he invented the cotton gin, nor Fulton when he constructed the first steam-boat, nor Morse when he perfected the telegraph.

This was all pure commercialism. Even if these worthies cared nothing for the financial side of their work and only sought to serve and benefit their fellow men, they could not be classified with the man who describes an unrecorded bug, or the one who makes a new but useless chemical compound. The latter work without the hope of direct money return for their labors. Therefore, theirs is the true method and the higher life even when their disinterested consecration to science is mingled with a hope that a little fame will bring them an increase in salary from some practical person or persons who appreciate their unselfish efforts.

However all of this may be, we know that the essence of any engineering work worthy the name is its independence. With this there is usually some degree of originality, as it seldom happens that the same problem repeats itself in every particular. What is more, with the independence and originality of the engineer must come character—confidence in his own mental processes and a willingness to shoulder responsibility in embodying his conclusions. A scientist may announce his discovery of the tidal evolution of the moon and yet be forgiven if later it should be shown that he is in error. Not so with the engineer. When his bridge falls under prescribed conditions of safe load, his own ruin as well as that of his structure is complete. Of all men living the intellectual life the engineer is the one most interested in sound and logical training for his profession and most intolerant of all shams. It is not surprising then that the one subject in secondary schools whose natural purpose is to train the student to severe logical and productive thinking should respond most fully to his influence. Neither is it surprising that from the ranks of the engineers should come the reformer who sees clearly the defects of our present mathematical work in the lower grades and who is moving powerfully to secure better conditions.

We may sum up what now seem to be the best ideals in secondary mathematics as follows:

These ideals come from the engineering professions.

They insist upon quality rather than quantity.

They insist that the problems shall be largely concrete and shall be worked out to an accurate numerical result.

They insist that the thought shall precede the form, that the symbol shall not conceal the thing symbolized.

They insist that systematic and progressive problems based upon every-day experience and observation shall be, to a much greater extent, the materials of education.

They demand that the several elementary mathematical subjects from arithmetic to the calculus shall develop side by side in the boy's mind.

They demand that the mastery of these subjects shall be more the work of the judgment than of the memory.

They demand that from first to last, at least during the secondary period, mathematical ability and the ability to think clearly, investigate closely and conclude correctly shall develop together, and to the extent that four well-spent years will on the average permit.

Those who formulate these ideas contend that they lead to the correct mathematical training for all professions and all careers.

It remains for us to consider the mathematical courses in our technical colleges. What is their relation to the development of the engineer? What shall they include? How shall they be administered? These are not new questions, neither has the last word been said in answer to them. Fifteen years spent in directing engineering mathematics gives the writer some excuse to undertake some further discussion of them.

Important contributions were made by Professor Mansfield Merriman in 1894, and Professor Henry T. Eddy in 1897, whose articles are published in the *Proceedings of the Society for the Promotion of Engineering Education*, Volumes II. and V. But among the most suggestive discussions during the last year, as well as all previous years, are the papers of some of our brightest electrical engineers presented at the joint meeting last July at Niagara Falls of the society just mentioned and of the American Institute of Electrical Engineers and published this year in the proceedings of both societies. To those interested in finding the best educational conditions leading to the average as well as the most important engineering operations of the day these papers come with peculiar weight and authority. Judging from the expressions of opinion contained in them the active engineer in his occupation, at least, cares nothing for the philosophic basis of the concept of number, nor for the geometry of non-euclidian space, nor for Grassman's *stufe* of the fifth or sixth degree, nor for computations of plane triangles when the sum of the angles is less than 180 degrees. These subjects may and should interest the professional mathematician, but the engineer asks first for the ability to use numbers rapidly and to carry numerical computations, no matter how complex, to an accurate conclusion. As for ordinary mathematics, including of course elementary geometry, algebra and trigonometry, the engineer should know them as he 'knows the currency of his native country. In other words, he ought to be able to make change with ease, quickness and accuracy—not as if one were in a foreign country in a constant state of painful reckoning.'

On a basis of barter modern business would be strangled. The very existence of commerce in the modern sense, in which the line of cost and profit is so finely drawn, would be utterly impossible without a standard currency. So without mathematics engineering would be a mass of empiricism and tradition. Instead of a pioneer leading the way in the progress of the people it would be an outcast trailing in the rear of every science.

This proposition that mathematics is the very bone and sinew of an engineering course needs no discussion. It is everywhere conceded. The extent and nature of the mathematical element in the curriculum, however, are two decided fluents with curves of opposite slope. More mathematics but fewer kinds seems to be the tendency. The opinion appears to be gaining ground that the purely descriptive and highly specialized and professionalized elements in our technical courses should be reduced, while more subjects with a mathematical basis, with long unbroken continuity and bound together with a strong logical element should command the attention of the student to the end of his undergraduate period.

Upon the question what mathematical subjects shall the undergraduate courses include in our technical colleges, opinions are decidedly at variance. Upon the four ordinary elementary subjects the sentiment is practically unanimous, but these should be principally taught in the secondary schools. The practical people, however, are inclined to relegate analytic geometry and the calculus to the scrap pile.

To such subjects as vectors, theory of functions, theory of groups, they allow no place whatever.

One can not but feel that this verdict against analytic geometry and the elementary calculus—not to mention higher subjects—is a great pity. Especially does it seem true when we recall that instruction in these two lines forms the principal mathematical element of the second and third years of the ordinary technical course and that the calculus itself is probably the most powerful and wonderful tool for investigation that the genius of man has ever contrived.

The student of mathematics who has reflected deeply upon the meaning and interpretation of its symbolic language knows that man, in his struggle for the mastery and direction of nature's laws and processes, has no more subtle and no more powerful ally than he finds in the calculus. The other subjects leading to it are conventional and highly artificial, but with this one we return to simplicity and operate with perfect ease and freedom in the realms of time, space and force.

As we find nature operating by growth, and force by insensible gradations, so over against that the calculus is the science of continuous number. Why then does the mathematician find so much in this, his favorite subject, while the practical engineer—even the one of great ability, proficiency and success—is inclined to think that time spent upon it is wasted or at least not employed to the best advantage? Why this great divergency in conviction?

No one will doubt the ability of our best mathematical instructors and teachers, nor their perfect familiarity with the matter they are teaching. But are analytics and the calculus—especially the latter—presented to the average student in the best way? Does not the formal smother the thought element and leave nothing but routine machine work upon symbols? As the student learns laboriously how to find the first derivative of a wide range of *rider* problems has he a faint conception even of what it is all about? Sir William Thomson, you know, said he did not understand an equation until he could make a model of it. Is the average student able to make a model of his operations with the differential calculus? And when he takes up the integral calculus and begins his attack upon a mass of algebraic and transcendental functions, using at times devices of great complexity and extreme refinement, does he usually walk by sight or by faith? Does he not often go forward long and painful journeys in utter darkness as to the meaning of it all, trusting, hoping, praying that by and by his teacher and his text-book will land him on solid ground and in the clear light to revel and operate in a new world of thought and action? How many men of good natural endowments, who are sorely needed in the higher ranks of the world's workers, become terrified in this period of distressing gloom; how many have lost individual initiative and independence and are content thenceforward to walk, not upright, vigorous, aggressive, daring, in the clear light of right reason, but by faith, humble and submissive?

Why do practical men almost unanimously place calculus among the dispensable elements of a technical curriculum?

The answer, of course, is very simple; they have never found any use for it, probably because they have never learned how to use it. Yet they dare not pronounce against it altogether. They know that Rankine and Maxwell were master mathematicians, and that through this mastery of the most powerful of tools they were able to do for terrestrial what Newton and Laplace did for celestial mechanics. In college the engineer has not learned to use the modern tool called the higher analysis; it remains to him as foreign currency. Out of college he has not time to learn its use. Are you a teacher of mathematics and did you pursue the subject under the direction of a master; yet how many classes did you yourself guide through the calculus before its hidden meaning, its range, its versatility, its power, were in any adequate measure revealed to you? How simple and how majestic it has now become! But if you were so slow in reaching the true light, is it to be wondered at that students who go over the subject but once and under conditions not greatly superior to those of your own college days should not see clearly and should not use what they so little understand! Because, as matters now stand, the man who does not repeat his course in calculus many times will fail to appreciate it and use it, shall we say that it should be cut out of the engineering courses and its place taken by more algebra, more trigonometry and more descriptive geometry, or shall we retain it and reform its presentation? The true mathematical teacher will always vote for the latter proposition whatever may be the attitude of the professional man on the faculty or the pressure from the outside of the practicing engineer. How, then, may the higher analysis in our technical schools be made effective as a true means of discipline and as a tool with which to equip the engineer in his life of investigation?

It is to be understood that the answer to this question here is not claimed to be *the word* nor the *last word* on so important a topic. It is *a word* to be taken for what it is worth.

1. The most effective teaching of the higher analysis will be possible only when the reforms in mathematical instruction referred to earlier in this paper have permeated the principal secondary schools.

2. The teacher should be saturated with his subject. Not only should he be strong and apt on the formal side, but more important still, its inner meaning should be clear to him and its close relation to the phenomena of the objective and subjective life. Some contend that the only man to whom the mathematics of a technical college can be entrusted is an engineer. Does that make any difference? Rather are not these the essential questions? Does the man know his subject? In his teaching can he assemble from engineering and other records the material that will vitalize his work? Is he in sympathy with engineering essentials and ideals?

3. Throughout the college course the teaching should be mainly concrete. The problem, say from the physical sciences including engineering, should first be presented concretely. It should then be stated in mathematical symbols. The operations performed upon the symbols should be accompanied by drawings or models, the final result reduced to numerical form and then interpreted in language. Upon every problem the student must bring to bear the whole range of his acquired powers and be taught to select the shortest method within his ability.

In other words, all typical problems should receive a threefold consideration: (*a*) Its statement in words, and the statement in words of its solution when effected; (*b*) its graphical statement and solution involving geometry and mechanical drawing with squared paper; (*c*) its analytic statement and solution, ending with a numerical result.

4. The purely formal should be presented as a necessity arising from the so-called practical and in order that a body of knowledge and technical ability may be accumulated which will give the student easy control over the practical in whatever one of its various forms experience shows that it may arise.

5. The problems chosen should be progressive in character and their mastery should amount to a complete laboratory course in all that part of the higher analysis in which it is desirable that the engineering student should be well versed.

6. The course should be lecture and seminarium and individual, more after the manner of the German Technische Hochschule. The text-book should become a book of reference. The instructor should know clearly and be able to state accurately the limitations of his methods; but abstruse

discussions of obscure points should be postponed as long as a due regard for logical development will allow. Time is wasted in removing difficulties whose existence and importance the student has not yet recognized.

These are some of the necessary extensions into college work of the reformation now urged upon the secondary schools, and though every one of them seems familiar enough when taken separately; all together their united application to the mathematical courses in our technical colleges amounts to a departure from our present traditional methods little short of revolutionary. Yet isn't this the thing our engineers are demanding, and isn't this the logical way to train an engineer in higher mathematics? Isn't it the way to approach the higher mathematics anywhere or in any kind of a school?

The pure mathematician may object and exclaim, What is to become of our curricula which have been evolved after so many years of intellectual conflict! The rule is so much algebra, so much geometry, so much trigonometry, so much analytical geometry and so much calculus. At the end the student has passed with greater or less success so many formal examinations upon so many formal topics and his acquirements are supposed to range somewhere between the maximum and minimum grade of passing. But are these the questions which the enlightened educator of today is asking? Is it not *How much power?* A dry, barren, fruitless familiarity with a number of highly specialized and unrelated things can not be education. The engineer demands that the unity of the mathematical branches should be emphasized and that they should accumulate in the soul of the student not as dry and unrelated facts, but as a magazine of energy.*

You may ask for some definite concrete expression upon the way that the study of calculus should be undertaken. This paper will close with an attempt at a brief answer to this question.

We will suppose that experimentally or otherwise the student is familiar with the equation of falling bodies $s=\frac{1}{2}gt^2$. By this time also the student must be somewhat skilled in the use of squared paper and acquainted with this curve itself through its application to parabolic mirrors or otherwise. Perhaps, our parabola had been studied from its geometrical side as a conic section. It now takes on a symbolic meaning, for it gives in a certain sense a picture of the first law of falling bodies. But does the student grasp the full meaning of the picture? Using the approximation $g=32$, we have a numerical equation. The abscissas of the curve represent elapsed time; the corresponding ordinates represent total space traversed. At some point on the curve proceed geometrically and analytically to construct the tangent, at every step making a threefold interpretation, one of the curve, one of the analysis, and one of the fact connected with these in the familiar phenomena of a falling body. Show the limiting position of the secant, deduce the number towards which your successive numerical approximations tend, and connect both of these with the velocity of the body at the point considered. Draw the tangent and show

* Little has been said in this paper about descriptive geometry and mechanical drawing as necessary parts of a general mathematical training. Both of these subjects are of the highest value as disciplinary studies. They make definite and effective other mathematical material. Is not one reason for the barrenness of mathematics in university courses the fact that these branches simple though they are, have been so long neglected? Do we not find one important explanation of the effectiveness of technical college mathematics in the fact that these subjects are always a large part of a technical training?

how it represents uniform velocity. Show that the results reached at one point on the curve are general and apply equally well to every point and that everywhere on your curve the geometrical tangent and your analytic limit interpret each other and give the rate or velocity of the falling body.

Note that the tangents are changing, that the corresponding numbers are changing and that these constitute a rate of change of velocities. Show graphically the oblique straight line representing the changing velocities. Give its graphical, its numerical and its nature interpretation. In the same way study the line parallel to the axis of abscissas representing gravity. Study the graphs and their relation to each other. Study the series of numbers resulting from the selection of equal increments along the X-axis, the relation, therefore, of these operations to the theory of number series. Connect the first differential coefficient with the tangents and with rates, the second with the changes of tangents or of rates of tangents, and thus with the thing in this problem that produces the changes of velocities, that is, with the force of gravity. Note the deformation of the original curve if the resistance of the air had been considered and its influence accounted for by some simple law. Construct the curve of the body projected upwards. Let up and down destroy each other, so that the ordinates at each point will be the algebraic sum of opposite motions. Note the point in the curve when the projected body is for an instant stationary in the air. Observe its connection with the first differential coefficient. Note the deformation of the curve due to the resistance of the air acting according to some assumed law.

Similarly, construct approximately the smooth integral curve which represents the movement of a steam railroad train from station to station fifty miles apart. Connect the contour of the curve with velocities and with forces, including in the latter the steam in the cylinder, gravity assisting or retarding, friction and air resistance always retarding. Note how the second differential coefficient carries us back to steam in the cylinders, the third to the causes leading to a variation of the artificial forces, such as fuel, skill in stoking, etc. Pursue maxima and minima problems in the same way. But now, instead of a rate of change directly dependent upon a conventional unit of time, we have relative rates of change and we quickly enlarge our ideas of the meaning and application of the first and second differential coefficient. We can safely begin the formal element of the subject. Even then we should continue the diagram and its interpretation, though we may be utterly unable to set the highly artificial equation over against any definite problem known to exist in nature.

Just as differentiation always has a symbolic interpretation in tangents and rates, so the integration of any expression may be interpreted as the finding of an area.

From engineering we have a remarkable series of connected quantities and these may be selected, as given by Professor W. K. Hatt in the *Railroad Gazette* of December 23, 1898, for illustrating the cumulative effect of successive integrations. Five successive diagrams used in engineering practice are connected by integrations. These are in their order the load diagram, the shear diagram, the moment diagram, the slope diagram and the deflection diagram.

But it is not necessary to enter further upon specific illustration. The higher analysis is replete with problems which the skilled teacher may use as stepping stones by which he may help the student to pass with safety to higher and higher mathematical attainment. Step by step he masters his method while he is gaining a clearer insight into the causal relations of things about him.

The thought element is ever dominant. He goes from strength to strength until no task seems too difficult for his disciplined powers.

Two young men stand before an intricate machine. They are told that their success in life depends in large measure on their ability to understand and use it. One examines piece by piece the parts of which it is composed. He discovers the way in which these parts are connected, the material of which they are made, their size, their strength, their beauty. After long and arduous study, he knows very much about the machine but he can not put it in motion, he can not make it work, he can do nothing with it except to admire its perfection of form.

The other student begins to construct another machine like the one shown him. As it grows under his hands, he is constantly using it for every operation to which it can be applied. As it approaches completion he admires more and more its adaptability and wide range of useful applications. Its beauty no longer affects him greatly, but he is lost in wonder and admiration before its marvelous power. This power he harnesses to the car of progress and he himself becomes one of the benefactors of his race.

Do we need to stop long to discover who is the 'man thinking'?

In later years mathematical instruction in this country has greatly improved in its thought content, but it has responded slowly and conservatively to modern methods. We are still more English than German. In the work of training a master of the physical sciences the text-book and the senseless repetition of words and formulas falling upon the dull ear of an instructor half asleep have been replaced by the lecture, the laboratory and the seminarium. Why should not mathematics, so intimately related to them, follow their lead and partake in the benefits of modern methods carried to their legitimate and logical completion?

C. A. WALDO.

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THE AMERICAN PHYSICAL SOCIETY.

THE winter meeting of the American Physical Society was held in cooperation with Section B of the American Association for the Advancement of Science at St. Louis, joint sessions being held on December 29–31, 1903. The business meeting of the Physical Society was held on December 30, and the program for that day consisted of Physical Society papers.

The meeting was a distinctly successful one. The program, consisting of twelve papers, was as large as could be satisfactorily handled, and contained several papers of exceptional interest. While comparatively few eastern members were present, the attendance was, nevertheless, well up to the average of previous 'annual' meetings. The large attendance of physicists from the middle west, most of whom are only rarely able to attend the meetings in New York, offered a strong argument in favor of more frequent meetings in that part of the country.

At the annual election the officers of the past year were reelected, *i. e.*,

President—A. G. Webster.
Vice-President—Elihu Thomson.
Secretary—Ernest Merritt.
Treasurer—William Hallock.
Members of the Council—Messrs. E. Rutherford and W. S. Franklin.

It was decided to hold the spring meeting of the society (1904) in Washington, this action being taken in consequence of a cordial invitation extended to the society by the Philosophical Society of that city. Not only is the local membership of the society in Washington large, but the ad-