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THE FUNCTION OF RESEARCH IN ENGINEERING EDUCATION[1]

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. . . . to sift the grain from chaff,
Get truth and falsehood known and named as such.

MORE than thirty-five years ago Dr. Robert H. Thurston, then director of Sibley College, was a guest at the University of Wisconsin where I was a youthful and rather new member of the faculty trying to build up suitable laboratories of electrical engineering with inadequate funds. We had much extemporization by teachers and students in the use of equipment. This brought to the surface the peculiarities of each piece of apparatus used in unusual relations, and we were having a grand time experimentally determining the reasons for various observed phenomena which hitherto had not been fully explained. Dr. Thurston walked about our few and meager machines while I told him what we were doing with them and how they served as elements of student work. Then he simply remarked that he was pleased to find us "carrying on so much research".

I confess that this remark of his struck me with rather profound surprise and the impression that it gave me is still rather vivid. We (the teachers and students in electrical engineering) were testing and investigating various strange or unfamiliar effects, but this was all in course of satisfying our curiosity regarding unexplained features of the instrumentali-

[1] Address delivered at opening session of thirty-ninth annual meeting of the Society for the Promotion of Engineering Education, Lafayette, Indiana, June 17, 1931.

ties in our field of engineering life. I presume that none of us had thought of it as "research". Research at that time rested in my mind as something leading up to a multiple volume treatise like Faraday's "Experimental Researches", Maxwell's "Electricity and Magnetism" or Helmholtz's "Sensations of Tone"; or perchance culminating in revolutionary discovery, like Faraday's researches in electromagnetic induction or Newton's investigation of motion and gravitation. Our activities were simple investigations carried on to satisfy inquiring minds and executed in the daily life of a group of students preparing themselves for their professional work. If these activities were research, it seemed an inevitable conclusion that research is a part of engineering education. The conclusion is sound. Research not only has a function in engineering education, but it is more, it is an integral part of properly conceived engineering education.

The recorded early part of the lives of Michael Faraday, Joseph Henry, George Stephenson, Alexander Holly and a host of others to whom we are indebted for the present status of engineering and the engineering industries shows plainly that the principal quality of their education, which primarily was self-education, arose from just such activities as were characterizing the electrical engineering laboratories in the University of Wisconsin to which I have referred. It was truly education to such men—in some instances almost the only education they secured in youth; it also was research of moderate order and Dr. Thurston was right in dubbing as research the activities going on in our Wisconsin laboratories.

However, I prefer to call such rudimentary or elementary research an exercise of the spirit of inquiry or scientific curiosity, and make the latter a definite feature of engineering education, to which it pertinently belongs. Phenomena and their interrelations command the engineering life, which is thus distinguished from the more arithmetical life of a merchant-prince or a country banker. Inquiry regarding phenomena may be analytical in character, calling for pencil and paper. It perchance may be philosophical in nature, calling for argument or debate. But such inquiry is most fruitful when originally unfolded in the laboratory, or the validity of its analytical or philosophical conclusions have been tested there. The laboratory of physical experiment is an eminent aid to the analytical and philosophical inquiries by affording pragmatic tests of the soundness of original analysis or philosophical synthesis, besides also of itself being a place for original discovery. Words alone are not enough. The individual must exercise the habit of seeing and investigating for himself.

Joseph Henry one time nicely stated in words one of those platitudes that ought to be commonplace elements of every engineering teacher's processes, but too often are forgotten because they are only platitudes: "There is a great difference between reading and study; or between the indolent reception of knowledge without labor, and that effort of mind which is always necessary in order to secure an important truth and make it fully our own." The crystallized hindsight of the printed text-book page and the conventional classroom lecture do not alone stimulate most minds to the necessary effort; but a ready instrument for such stimulation lies in the practice of investigation carried out under sympathetic counsel and direction by suitable leaders. For sufficiently advanced students the seminar consisting of a student group, carrying on research under the guiding influence of lectures by a professor, mutually discussing their inferences and conclusions, also perhaps testing them in the laboratory, and writing dissertations summarizing results of their inquiries, is a practice of proved success in higher education.

This is an age when most intellectual individuals prefer to command a great project rather than to inscribe a Greek verse, and this mental attitude has brought large rewards to the common people of the world as well as to the individuals who have dared on their behalf to deal with nature in new ways. The fine arts and the decorative arts lose no distinction by sharing their pedestal with the products of creative-minded men who concentrate their attention on those things that contribute to the physical welfare of the human race. Indeed, this sharing has brought to the graceful arts an incense of appreciation which has steadily broadened without sacrifice to its depth. The scientists and engineers lead the van of the daring ones, but none will "dare" except he possesses an investigatory spirit and a resourceful mind. If formal education is to do much for such men in their youth, as we claim is a prime object of engineering education, the education must be directed to research of the varieties that encourage the spirit of inquiry and add to the store of intellectual and manipulative resource. Lacking this, our disciples will not be among those who lead in the conquest of unknown regions and the marginal areas that face the engineering industries—which conquest may, decade by decade, confer yet larger and more widely-spread benefits on the common members of the human race. Book learning, and instruction about facts of nature and man, are a background for stimulating intelligence and arousing ambition, but alone they are static and insufficient to stiffen the students' backbones and inspire them to balanced initiative, originality and self-reliance.

The boon of such stiffening and inspiration, along with lessons in the joys of accomplishment, may be conferred on our students by leading them into the paths of research, minor and easy paths at first but becoming more excitingly difficult according to the advancement of each student. The achievement of this process is difficult. Nevertheless, experience shows that the effort is worth while and observation indicates that the greatest centers of engineering education have become great and attractive to ambitious students because of willingness in those centers to make the effort.

Such reflections are fully supported by experience and observation. They may be verified by examples. The department of electrical engineering at the Massachusetts Institute of Technology and the like department at Cornell University share the honor of directing the earliest established formal curricula in electrical engineering. The world's practice in this field has largely grown from these two examples. These early curricula were both established in the academic year 1882–3, one late in 1882 and the other early in 1883, and students in each first received degrees in course in June, 1885. In those days the action of electrical machinery was not altogether understood and often was crassly misunderstood; the characteristics of electric circuits under transient conditions had not been extensively explored; equipment was meager; instruments for measurement were inadequate; text-books were not available; and instruction, as a matter of necessity, was by the seminar type of study and investigation carried on by students under direction of the professors. Some lectures were provided, but mostly the students studied the character of machines, instruments and circuits in the laboratories and reflected on the possibilities and consequences of modifications. Much extemporization was exercised to demonstrate the results of changes in combinations. If a machine or device was lacking and could not be borrowed in some form, students made it. The data for complete mathematical analysis were lacking, and the possibilities of many forms of analysis, now in common engineering use, were only showing over the horizon as an absorbing stimulus to individual ambition and study. The setting was one of vital and whole-souled intellectual interest. Examining the rosters of men who were in the early classes of these two courses discloses a notably high proportion of their members who became of high place in electrical engineering.

At a somewhat earlier date President Morton, Professor Thurston, Professor De Volson Wood and their associates at Stevens Institute of Technology were developing a similar situation in mechanical engineering. In that period Professor Thurston established a laboratory for investigation in the engineering sciences. Nowadays we would call it a research laboratory. These men were trail breakers in mechanical engineering education, and it may be significant that the roster of early graduates of Stevens now reads like a "Who's Who" in Mechanical Engineering. The influence of those graduates during the unfolding of American industries has been tremendous and magnificent. Still earlier, a devoted group at Rensselaer Polytechnic Institute worked through a similar development period in civil engineering education; and the large influence ultimately impressed by their students on American engineering is sufficiently well known.

These examples are typical and selected without overlooking the meritorious results from other early engineering schools and curricula established in the last half of the nineteenth century. Perhaps the interesting influence in chemical engineering of the courses of study in that branch that came into being a quarter of a century ago, or thereabouts, partly arises from a similar set of conditions growing out of applications of science in newly growing industries, which stimulated inquiring minds and led instruction through the paths of investigation.

Many of our present students will be inspired to mature performances just as notable as those of their predecessors, but can we unqualifiedly assert that those thus achieving will comprise an equally large proportion of the present generation of students as in the examples above referred to? I think that it is generally agreed that the answer to this question is "No." It may be lightly commented that now there are more students in the engineering schools and that they are less ambitious and scholastically less well prepared to pursue their courses of study in engineering; but this is not a sound rebuttal. There now are more engineering schools and many more professors employed in them, compared with the numbers at the close of the nineteenth century. Are we ready to concede less intellectual vitality, devotion and ability in the individuals of our group of teachers than in the corresponding group of forty years ago? That would be an ignominious confession. In my opinion there is as much intellectual vitality, devotion and ability per unit in our group to-day as there was forty years ago. The information disclosed in Vol. I of the Report of the Board of Investigation and Coordination of this society supports the opinion:

> The educational standards of the present group of engineering colleges taken collectively compare favorably with those of all other equally comprehensive groups of undergraduate colleges. This statement holds for the adequacy of their physical facilities, the number and qualifications of their teachers, the level of their ad-

mission requirements, the content and rigor of their curricula, the soundness of their scholastic standards, the extent and quality of their research activities, and their expenditures per student.

I will add the comment that an investigatory spirit and achievement are more important attributes for the engineering teacher than higher degrees, and we must fix our faces unwaveringly against a policy, now somewhat established in the colleges of arts, of making staff appointments from doctor's degrees attached to second-rate men in preference to selecting first-rate men without the doctorate when the first-rate man can not be secured along with the doctorate. You must remember when I say this that I am an active proponent for the advantage that graduate study confers on those who go into teaching and also for many of those who go into industrial life. But there are good reasons why a doctor's degree, as a badge, is not an important requisite for a teacher of engineering subjects. The man with neither fire nor industry is but loss in this occupation. Even where location and means preclude formal organization of research, this character in the teaching needs be kept foremost in the minds of the teachers. The opportunity for its exhibition is not lacking in any of our properly administered engineering schools. It should be the object to saturate our students in an aura of resourcefully productive thinking and doing. Plenty of this aura must emanate from the spirit of those who teach the classes, to be effective on the students, and not be the outcome alone of those who direct departmental affairs or those who confine their endeavors to formal research. Formal and external badges of learning, however carefully conferred, can not compensate for deficiency of these qualities in the teachers.

Observation leads me also to believe that our entering students are proportionately as well prepared to pursue their engineering studies as corresponding students were forty years ago. At the present time the number of listless students is numerically greater, but I doubt that the proportion of such in the total is greater, or that the preparation and ambition of most of the students are relatively less satisfactory, or that the proportion of adventurous intellectual spirits is less.

Students suitably infected with the spirit of investigation will smilingly carry heavy allotments of mental and physical work and ingratiatingly intimate a willingness for more. About eighteen years ago a large industry offered to the department with which I am related a considerable annual sum of money to be used over a period of improving our advanced instruction and research. We embraced the opportunity to keep the research so much in the consciousness of junior and senior students, as well as graduate students, that it has had a notably stimulating influence. Those of us in that setting think well of the result of this coordination of the teaching and research.

It also may be suggested that the field of the unknown has been exhausted in engineering and that there is nothing left for the inquiring mind, but that comment is only made by those who do not observe for themselves. It is sufficient to answer: Look around and observe, study the development of engineering in the past and present and you will discover a speed and width of the front of growth in all branches of engineering which now rivals if not excels any previous era.

This is a period suffering from a flood of predigested text-books, reliance on conventional laboratory assignments and presentation of formal lectures. The cry is made that these processes are necessary in order that the students may learn all that they should learn, and that there is no time left over for cultivating an investigatory spirit. My answer is that resourceful foresight and self-reliance (set against pepsinized hindsight and common industry) will always win in the end; and we develop the winner when we develop investigative spirit and resourcefulness, even if some store of secondary facts is neglected for lack of time. Our situation is illustrated by the old ditty:

Could man but be sure that life would endure
As of old, for a thousand long years,
What things he could know, what deeds he could do,
All without hurry or care.

Recognizing that life is short we must reconcile ourselves in education to selecting the most serviceable of various possible processes, remembering that the sweep of time does not permit us to embrace more. In making our choice of processes, however, we must try to make sure that the choice is of the most serviceable.

Albert W. Smith, known to most of you as former director of Sibley College, and before retirement as acting president of Cornell University, but to some of us known earlier as a remarkable teacher of machine design, held that no teacher should teach from a text-book written by another. This is a way of saying that the work of the engineering teacher should constantly grow under his hand; and also is a way of stating that the inquiring, forward-looking mind and the spirit of investigation are essentials to foremost engineering teaching. Unhappily, text-books written in that spirit often are received coldly by the teachers, as "too hard," and a preference is exhibited for the predigested, backward-survey types. This has a temporary justification among teachers loaded with an excess of classroom assignments, but it is one of our collective duties as a society to show to college administrative officers a better way. Students who possess ambition and courage to study, reflect and learn under guidance ultimately may go far; but those who insist that they are paying their money "to be taught" are out of place in an engineering school.

Can any one doubt that the influence on their students and in engineering education of, for example, Irving Church, Mansfield Merriman and George Swain was in large part due to their resourceful originality and investigative spirit, standing foremost day by day as an example before their students? Engineers must deal with physics, economics and psychology, materials and forces, the philosophy of wealth (in the technical sense), and man. It is not a mental accumulation of facts alone that fits young men for doing this, but an understanding of interrelations of facts and the methods of detecting and identifying facts is of the essence. Our theories of action, relating to man or to mechanical design, are formulated from relatively few fundamental facts associated with a multitude of keenly recognized permutations of their relationships.

Detecting and identifying facts and discovering their varied relationships is research. Properly directed research is a potent instrument to arouse the ambitions and exercise the reasoning powers of students. It also teaches them to use foresight in planning and a responsibility for carrying through. It exposes them to early observation of the many faceted purposefulness and everlasting persistence of nature. It may result in important discoveries, which is another function. Universities and colleges (including engineering schools) have several functions to perform. One of these is the search for truth, and in science we interpret this as seeking for new facts, disclosing previously unobserved interrelations, and more fully illuminating facts and relationships previously announced but still partly obscure. In engineering we weave this function into a fabric along with economics and psychology and have a still more complex compass of research than characterizes any exclusive science. The field is magnificent and must be cultivated. Research is an inspiring part of the life of colleges. The spirit for establishing research laboratories and foundations in engineering schools is a presage of good educational spirit in the schools. The proper interpretation of the situation is important.

We must remember that universities and colleges have education for their prime function; and it being my thesis that research is part of engineering education, students of suitable advancement should be invited into the research precincts to there take up tasks. To set up research laboratories and libraries and bar out students of suitable advancement from pursuing work therein would be inappropriate to university ideals and to the weaving of the best fabric of engineering education. Research laboratories, dedicated to and carrying on fundamental research of high order, gloriously serve the advancement of mankind through their investigations and discoveries. When so directed that the atmosphere of independent achievement is allowed to spread into the haunts of upper-class students, as well as to graduate students and teaching staff, they collaterally make large contributions to educational results and thus their value to civilization is multiplied.

THE UNSOLVED RIDDLE OF THE SOLAR SYSTEM

By CARR V. VAN ANDA
NEW YORK, N. Y.

The public is being played upon and utterly misled by the dreamery of the rival mathematical astronomers and physicists.—*Professor Henry E. Armstrong, in Nature, Aug. 23, 1930, p. 275.*

Dr. Harold Jeffreys, university lecturer in mathematics and fellow of St. John's College, Cambridge, expounds in *The New York Times* of May 3 his newly developed theory that the planets of the solar system owe their origin to a shearing collision between the sun and another star. The article is a summary of two papers which Dr. Jeffreys contributed to the *Monthly Notices* of the Royal Astronomical Society, Vol. LXXXIX, Nos. 7 and 9, 1929. Because this theory, in contrast with its original rather unexcited reception by scientists, is now presented as something of exceptional importance; and because the present version indicates, as the original papers did not, an apparent final abandonment of Sir James Jeans's famous development of the "tidal theory," by the man who was long Sir James's chief supporter, an examination of both theories may prove to be worth while.

The essential feature of the new theory is that at the end of the collision there was drawn out between the two bodies a ribbon of matter in which circulation had been set up by their opposed velocities. This ribbon presently broke up and the parts condensed