MICHAEL FARADAY AND THE ART OF LECTURING

An intimate understanding of Faraday's unique approach toward education adds new dimensions to one's perspective of the old art of teaching

RAYMOND J. SEEGER

Michael Faraday's contributions to our understanding of electrical and magnetic phenomena are generally well known. Less familiar to many people is the importance of lectures in Faraday's own self-education and his subsequent teaching of others. He possessed an exceptional capacity for research *and* communication, a quality still evident in The Royal Institution, of which he had been director. This capacity was evident to all, both young and old, in a manner that was strikingly unique. For in his lectures he expressed all of the emotional and intellectual attributes of the natural philosopher possessed of genius. Lectures, for Faraday, reflected an approach to life involving all aspects of the personality in intimate relation to phenomena.

A legacy of lectures

What is our heritage from Faraday's lectures? May I take a clue from Faraday's own practice? In a sermon delivered at London (7 June 1863) he apologized for his presentation on that occasion: "I cannot do better than read to you the words of Scripture, instead of multiplying my own words."[1] Accordingly I shall have recourse primarily to Faraday's own statements as self-evidence of our indebtedness to him.

Faraday's experience with lectures began in his teenage years. As early as 1809 he attended the Wednesday evening lectures on natural philosophy in the house of John Tatum; later (1813) he joined the City Philosophical Society, which had been founded by Tatum in 1808. In 1812 he was fortunate to hear the brilliant Sir Humphry Davy give four lectures to the fashionable audiences that frequented The Royal Institution.

Lectures occupied much of Faraday's mature life also. His first (seven) lectures were given at the City Philosophical Society in 1816. When appointed (1825) director of The Royal Institution, he established the course of Christmas Lectures to a Juvenile Auditory, which were given first in 1826 by J. Wallis. Faraday himself gave 19 of them beginning with the first series in 1827–28, then only occasionally, but annually from 1851 to 1852 until the last in 1860–61. In 1848–49 he first gave the sequence entitled, "The Chemical History of a Candle." Faraday also instituted Friday Evening Discourses in 1827; he gave six of the 17 that year and his last one on 20 June 1862. In addition he gave occasional lectures at The Royal Institution such as the first ones on chemical philosophy and manipulation (published in 1827). Henry Bence-Jones, the secretary of The Royal Institution and a friend of Faraday for 30 years, stated at the end (1830) of the first volume of *The Life and Letters of Faraday*,[2] "He [Faraday] had probably saved the Institution by taking the most active part in the establishment of the Friday evening meetings." Towards the end of the second volume the author remarked, "For thirty-eight years his lectures were the life of The Royal Institution." Although Faraday declined a call in 1827 to be professor of chemistry at the newly formed University College in London, he lectured for a number of years (1829–51) at the Royal Military Academy, Woolwich. In the later years he was devoting the greater part of two days a week to this enterprise.

The art of lecturing

In a letter (1846) to the secretary of the institution, he advised, "As to popular lectures (which at the same time are to be scientifically *respectable* and *sound*), none are more difficult to find. Lectures which *really teach* will never be popular; lectures which are popular will never *really teach*. They know little of the matter who think that science is more easily learned or taught than A B C; yet who has ever learned A B C without pain and trouble? Still lectures can (generally) inform the mind."[2] In The Royal Institution's 1960 brochure one finds much valuable "Advice to a Lecturer"[3] distilled from Faraday's own letters. For example, with respect to

MICHAEL FARADAY LECTURING at The Royal Institution, 1855. Faraday's assistant, Sergeant Anderson, stands behind him on the platform. Seated in the first row to Faraday's right are scientists John Barlow and Henry Bence-Jones. Reproduced with the consent of The Royal Institution, London.

the lecturer himself, "He should in no case forget that he is in their [audience] presence . . . he should never, if possible, turn his back to them . . . The most prominent requisite . . . is a good delivery." He stressed orderly arrangement of material: "I always find myself obliged, if my argument is of the least importance, to draw up a plan of it on paper . . . I have a series of major and minor heads in order." Speaking of lecture notes, he said, "Although I allow a lecturer to write out his matter, I do *not* approve of his reading it." He commented even about diction, "A lecturer should endeavour by all means to obtain a facility of utterance and the power of clothing his thoughts and ideas in language smooth and harmonious and at the same time simple and easy." He cautioned about general behavior, too: "I would by no means have a lecturer glued to the table or screwed to the floor . . . A lecturer falls beneath the dignity of his character when he descends so low as to angle for claps and ask for commendation." With regard to experimental demonstrations he urged, "An experimental lecturer should attend very carefully to the choice he may make of experiments." . . . "Diagrams," he insisted, "should be left in the view of the audience for a short time after the lecturer himself has explained." He was particularly concerned about the audience's attentiveness: "Digressions and wanderings produce more or less the effects of a complete break or delay in the lecture, and should never be allowed . . . For the same reason (namely, that the audience should not grow tired) I disapprove of long lectures [that is, greater than one hour]." Even the lecture room was considered: "The best form for a lecture room in general is without dispute a circular one . . . for by far the greater part of Philosophy day light is the most eligible and convenient . . . admitted if convenient at the top." No wonder Edward N. da C. Andrade has concluded, "As an experimental lecturer Faraday was supreme. He took the greatest trouble in devising the experiment and in making sure that it would be successful and seen by everyone."[4] I believe that today we need better lectures in this style—not fewer (a poor discussion is certainly no substitute for a poor lecture).

Although the Faradays had no children, they were wont to borrow young

neighbors, nieces, and others for visits to the zoo and for holidays out of town. His interest in children is evident from his Christmas Lecture Series. Two of these series have been published *verbatim et literatim* from Sir William Crookes's notes: One, "On the Various Forces of Nature,"[4] was given in 1859–60 and published in 1861; the other, "The Chemical History of a Candle,"[5] was given first in 1848–49 and then in 1860–61, also published in 1861. Briefly, the outline of the one on forces reviews topics such as gravitation, cohesion, chemical affinity, heat, magnetism, electricity and the correlation of forces. The one on a candle considers a flame and its products of combustion, the atmosphere and respiration, as well as the carbon cycle. As with previous requests, Faraday himself had refused to publish the Christmas Lectures on the forces of matter because "the lectures without the experiments and vivacity of speaking would fall far behind those in the lecture room as to effect."[1]

When preparing for this article I reread these series of lectures and compared their essential features. First of all, I noticed the careful use of connecting links. In both groups each lecture began with a reference to the preceding one. Two of those on forces concluded with an introductory comment for the next one, whereas in the candle series all the lectures concluded with such a remark. For example, even in the opening remarks of the first candle lecture we hear: "I have taken this subject on a former occasion; and were it left to my own will, I should prefer to repeat it almost every year —so abundant is the interest that attaches itself to the subject, so wonderful are the varieties of outlet which it offers the various departments of philosophy." And later, "it will be a lesson to me in future to hold you more strictly to the philosophy of the thing, than to take up your time so much with these illustrations."

Raymond J. Seeger received a PhD in theoretical physics from Yale. He was a visiting scholar at Oxford University in 1961–62. He has received the US Navy Distinguished Service Award and the AAPT Distinguished Service Citation. One of his primary interests is in the humanistic aspects of the development and understanding of physics together with its literary and social interrelations. He is presently senior staff associate for research at the National Science Foundation.

A joyful approach

In these two lecture series three basic attitudes of Faraday stand out: joy, wonder and experimental thinking. His whole approach, indeed, was quite joyful: "I claim the privilege of speaking to juveniles as a juvenile myself."[5] John Tyndall, his successor, later commented, "His delight in a soap-bubble was like that of a boy, and he often introduced them in his lecture." This quality did not abate: "This boy-like buoyancy of his later years was astonishing." (One may recall that he actually used soap bubbles for investigating the magnetic properties of gases.) Regarding crystals in polarized light, Faraday exclaimed, "Look at these colours, are they not most beautiful for you and for me? (for I enjoy these things as much as you do)." He spoke of the kindling point "as most curious and beautiful." The word "beautiful," indeed, was one of his favorites.

Beauty itself, however, was merely one aspect of nature's wonder. More soberly, he reflected, "Now we philosophers—I hope that I may class you and myself together in this case. . ." His curiosity was truly that of a natural philosopher: "Always remember that whenever a result happens, especially if it be new, you should say, 'What is the cause? Why does it occur?' and you will in the course of time find the reason." There are countless examples of this approach: "You know very well that ice floats upon water . . . Why does the ice float? Think of that, and philosophise."

"Is not this curious to see that we can construct a magnet of copper?"

"What will you say when I tell you that my breath will put out that candle? I do not mean by blowing at all, but . . ."

"It is wonderful to think how few are the powers by which all the phenomena of nature are governed." Another favorite word—"wonderful"!

He was deeply concerned not only that he communicate his ideas, but also that others appreciate them sufficiently to perform their own investigations. "I think, however, that you boys ought to be shewn experiments you can make at home; and so here is a very pretty experiment in illustration of the pressure of the atmosphere."

"Here is a boy's experiment (and I like a boy's experiment)."

"I want to shew you the best ways of making these experiments. I am not afraid to shew you, for I wish you to make experiments, if you will only make them with care and attention, and the assent of those around you."

"I make this experiment because you can make it well at home."

"Here is another very pretty thing—the boy's sucker, only refined by the philosopher. We young ones have a perfect right to take toys, and make them into philosophy, inasmuch as now-a-days we are turning philosophy into toys."

Reasoning with phenomena

We moderns particularly need his emphasis on experimental thinking, including both his startling approaches and his reasoning developments. "The best illustration of such a point to us, as juveniles, is to shew the result of strong contrast"—a good description by Faraday of his own tactics. Crookes noted, "The Lecturer here traced the word 'juvenile' on the paper with one of the terminal wires." Faraday used the bursting of iron bottles enclosing freezing water, the burning of gunpowder under water, the greater burning of iron filings in alcohol than that of gunpowder, and so forth. He contrived to have a spark from a Leyden jar ignite a hydrogen bubble (balloon), air float in a jar of carbon dioxide, iron filings arch midair above a concealed horseshoe magnet, his own hair rise and a gas jet lighted by a spark from his finger, as he sat on an electrically insulated stool.

He was intent upon developing the applicability of reason to phenomena. "I must take care not to leave anything unexplained."

"Every step we are now taking brings us to a knowledge of new phenomena."

"I shew you of these experiments for the purpose of pointing out. . ." By modifying the actions of different substances, he admitted that he was trying "to make them tell us what we want to know."

"We shall now begin to understand more clearly our experiments and researches."

"The reason why I make the experiment in this manner is solely that I may cause the steps of our demonstrations to be so simple that you can never for a moment lose the train of reasoning, if you only pay attention."

"I shew this to you today, in order to enlarge your ideas of these things, and that you may see how greatly results are modified by circumstances."

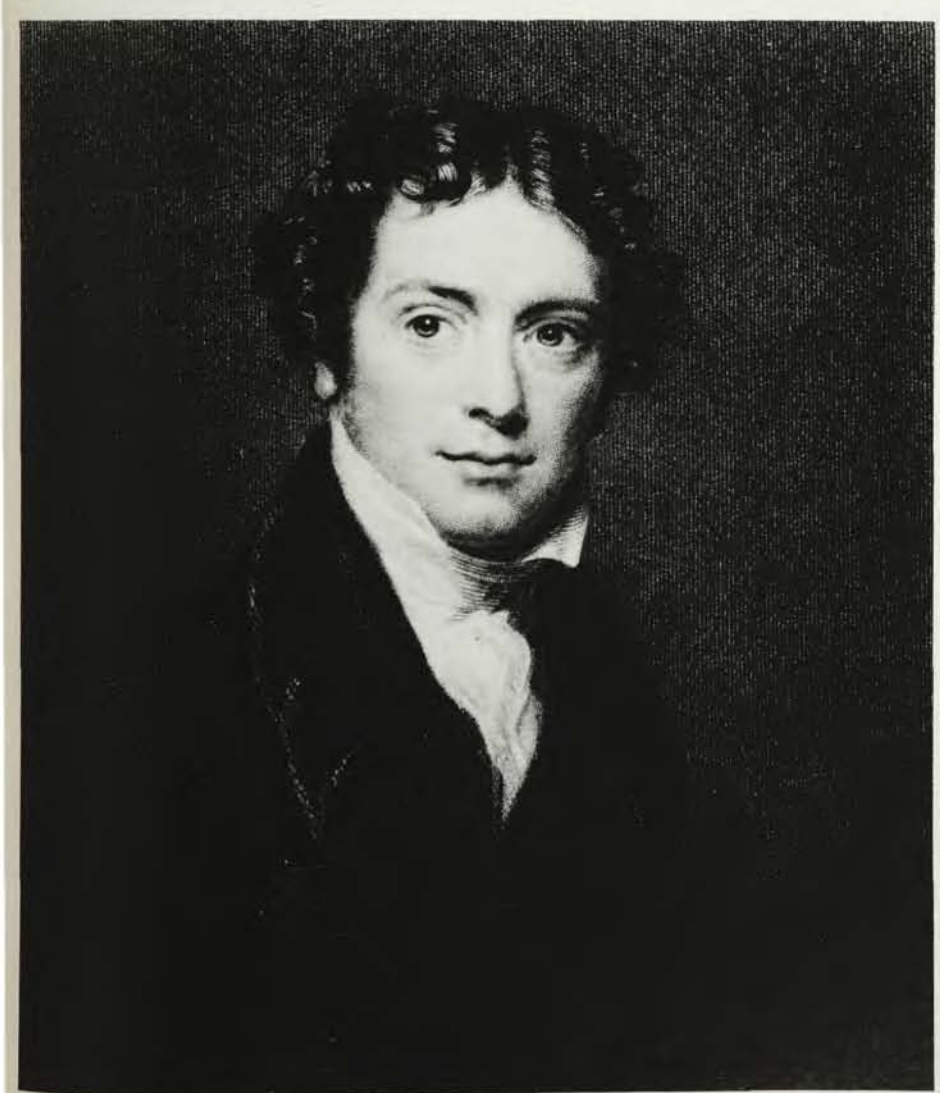
"You can, no doubt, by this time, generalize enough to be able to compare one thing with another." In his last candle talk he noted parenthetically, "We can now be liberal in the use of the word 'candle,' since we understand what it means."

"I will shew you another experiment, because this is an important part of our philosophy."

"I want you to put these different facts together in your minds." The carbon cycle he regarded as the "one great work of making the animal and vegetable kingdoms subservient to each other."

Faraday often made comprehensive summaries such as the following one in the first lecture on forces: "That power which caused the water to descend in the balance—which made the iron plate press upon and flatten the bubble of air [in India rubber]—which caused the swinging to and fro of the pendulum, that power is entirely due to the attraction which there is between the falling body and the earth." Again toward the close of the force lectures, "What then can surpass these evidences of the change of chemical force into electricity, and electricity into magnetism? . . . What more need I show you to prove the universal correlation of the physical forces of matter, and of their mutual conversion into one another?" Tyndall wisely concluded, "Faraday would never have been satisfied with a deduction if he could have reduced it to a fact;" at the same time, he noted that "facts cannot satisfy the mind."[6] Faraday, it is true, "had a deep-rooted belief in the simplicity of nature."

In 1959, Keith G. Irwin shrewdly observed, "There is nothing in the lecture about atoms, molecules, formulas, or equations. It is about the facts of chemistry; it is about chemical thinking as based upon facts."[5] For example, Faraday asked, "What shall we call it, A, B, or C? Let us call it O—call it 'Oxygen': it is a very good distinct-sounding name." I myself was impressed by the lack of historical citations and of quantitative experiments, apparently regarded as irrelevant to the primary goal, which was to achieve experimental thinking.



AS A YOUNG MAN Faraday entered into the services of a bookbinder and remained an apprentice for eight years. While binding books he came across Jane Marcet's "Conversations in Chemistry" and the "Encyclopaedia Brittanica."

Discovering nature's secrets

We should not neglect his significant obiter dicta, particularly those regarding the true, the beautiful and the good. James A. Thomson correctly noted, "What claimed Faraday's full strength was discovering the secrets of nature, not using them."[5] As Faraday himself pointed out at the start of his candle lectures and then demonstrated, "there is no more open door by which you can enter into the study of natural philosophy, than by considering the physical phenomena of a candle." In the last one he expressed his fundamental belief that "in the pursuit of science we first start with hopes and expectations; these we realize and establish never again to be lost, and upon them we found new expectations of further discoveries, and go on pursuing, realizing, establishing, and founding new

MICHAEL FARADAY CHRONOLOGY

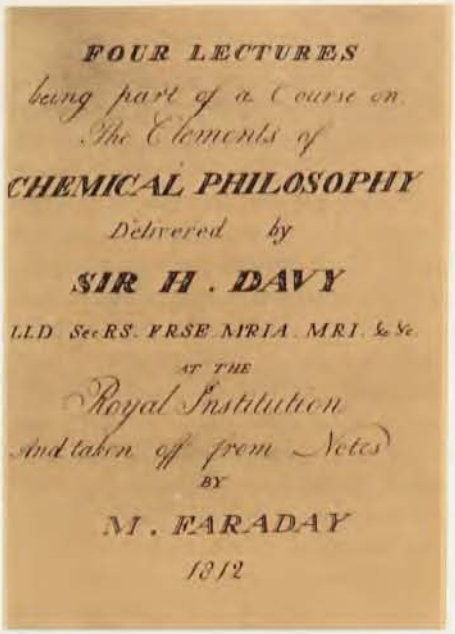
1791	Born 22 Sept. in Newington, Surrey, London.
1804	Employed as errand boy for bookseller and bookbinder (George Riebau).
1805	Bound 7 Oct. as apprentice for seven years to Riebau.
1810	Attended lectures of John Tatum at the City Philosophical Society, delivered first lecture.
1812	Attended four lectures of Sir Humphry Davy at the Royal Institution (RI), applied to Sir Joseph Banks, president of the Royal Society, for scientific position (no reply).
1813	Employed 1 March as laboratory assistant at RI, attended Davy on Continental tour as amanuensis.
1815	Returned in April to England, became assistant and superintendent of the apparatus of the laboratory and mineralogical collection.
1816	Published first scientific (chemistry) paper, "An Analysis of Naturally Occurring Caustic Lime."
1821	Married Sarah Barnard, 12 June (they lived at the RI), joined the Sandemanian Church a month later, investigated steel alloys, discovered the motor effect, appointed superintendent of the house and laboratory of the RI.
1823	Liquefied chlorine, first secretary of Athenaeum Society.
1824	Lectured in RI laboratory.
1825	Discovered benzene, instituted Friday Evening Discourses at RI, appointed director of the laboratory of RI.
1826	Instituted Christmas lectures for children.
1827	Published "Chemical Manipulation," declined Chair of Chemistry at the University of London.
1829	Began lecturing at Royal Military Academy, Woolwich (until 1851), reported on optical glass investigations.
1831	Discovered electromagnetic induction and the dynamo, published first of series of papers on "Experimental Researches in Electricity," [reprints published in vols. I (1839), II (1845), III (1855)]—spoke first of magnetic lines of force.
1832	Verified the magnetic effect of moving static electricity, awarded Royal Society Copley Medal, awarded D.C.L. by Oxford University.
1833	Discovered the two laws of electrolysis (invented voltameter), appointed Fullerian Professor of Chemistry at RI.
1835	Began investigation of electrostatic induction (specific inductive capacity, scientific adviser to Trinity House (Admiralty).
1840	Became an elder in the Sandemanian Church (dismissed later, but reinstated 1860–64).
1841	Serious health breakdown.
1844	Described ice-pail experiment (conservation of electric charge).
1845	Discovered magnetic rotation of polarized light and rediscovered diamagnetism.
1846	Speculated on light as a transverse vibrator in impromptu lecture on "Thoughts on Ray Vibrations."
1847	Discovered paramagnetism of oxygen, other gases diamagnetic; first lecture on "The Chemical History of a Candle."
1848	Discovered magnecrystallic action.
1850	Investigated relation between magnetism and gravitation (negative).
1852	Paper "On the physical character of the Lines of Force."
1854	Lecture on "Observations on Mental Education."
1857	Moved to house on green near Hampton Court, declined presidency of the Royal Society.
1859	Christmas Lecture "On the Various Forces of Nature;" published final collection of reprints, "Experimental Researches in Chemistry and Physics."
1860	Submitted last paper (rejected by Royal Society).
1861	Resigned from RI as Lecturer, Christmas Lectures ("On the Various Forces of Nature," "The Chemical History of a Candle") edited and published by W. Crookes.
1862	Awarded LL.D. by Cambridge University, last scientific investigation (on effects of magnetism on spectral lines—negative).
1863	Elected foreign member of National Academy of Sciences of US.
1865	Resigned as RI superintendent.
1867	Died 25 Aug., buried in Highgate Cemetery (London).
1869	First Faraday lecture by London Chemical Society.
1873	Publication by James Clerk Maxwell of "A Treatise in Electricity and Magnetism," based upon Faraday's research.
1933	Original gravestone replaced by another simple slab.
1936	Publication of "Faraday's Diary" (8 volumes, T. Martin, ed.).

hopes again and again." A remarkable description of the experimental method! Faraday concluded the series on forces as follows: "What study is there more fitted to the mind of man than that of the physical sciences? And what is there more capable of giving him an insight into the actions of those laws, a knowledge of which gives interest to the most trifling phenomena of nature and makes the observing student find

> '. . . tongues in trees, books in the running brooks, Sermons in stones, and good in everything.' "

Faraday was enthralled by the beauty of nature: "Is it not beautiful to think that such a process is going on, and that such a dirty thing as charcoal can become incandescent?" Regarding jewels like ruby and diamond he meditated, "None of these rival the brilliancy and beauty of flame." He reflected that "most beautiful things are common."

At the same time, keenly sensitive to ethical implications, he noted, "All, however, that is fine and beautiful is not useful." Further, "it is not the best-looking thing, but the best-acting thing, which is the more advantageous to us." In pondering the passive properties of a gas such as nitrogen he commented, "It [nitrogen] is remarkably curious, and yet you say, perhaps, that it is very uninteresting [no combustion] . . . It does a most wonderful work, although you say on examining it, 'Why, it is a perfectly indifferent [chemically inactive] thing' "; that is, it retards respiration and carries away fumes. He viewed ventilation socially: "Now you understand the ground of the impropriety of the arrangement among the houses of the poorer classes, by which air is breathed over and over again." He himself conceived of "all Nature being tied together by the laws that make one part conduce to the good of another." He reminisced that "he [Davy] smiled at my notion of the superior moral feelings of philosophical men, and said he would leave me to the experience of a few years to set me right on that matter."[4] The aged Faraday, nevertheless, exhorted his youthful audience at the close of the candle series as follows: "All I can say to you at the end of these lectures (for we must come to an end at one time or another) is to express a wish that you may, in your



THE ROYAL INSTITUTION, a watercolor by T. H. Shepard, ca. 1840. At right is the cover from Faraday's notes from a lecture by Sir Humphry Davy. Faraday later wrote, "My desire to escape from trade, which I thought vicious and selfish, and to enter into the service of Science, which I imagined made its pursuers amiable and liberal, induced me . . . to take the bold and simple step of writing to Sir H. Davy . . . at the same time I sent the notes . . ." With consent of The Royal Institution.

generation, be fit to compare to a candle; that you may, like it, shine as light to those about you; that in all your actions, you may justify the beauty of the taper by making your deeds honorable and effective in the discharge of your duty to your fellowmen."

Reactions to his lectures

In passing, let us note a few impressions recorded by some of his hearers. Lady Pollock remarked after his death, "He was completely master of the situation . . . It was an irresistible eloquence, which compelled attention and insisted upon sympathy. . .A pleasant vein of humour accompanied his ardent imagination, and occasionally, not too often, relieved the tension." Lady Owen commented about a lecture on attractive forces (1856), "He made us all laugh heartily; and when he threw a coal scuttel full of coal, a poker, and a pair of tongs at the great magnet, and they stuck there, the theatre echoed with shouts of laughter."[4] Bence Jones summarized the general opinion: "In his Juvenile Lectures, his simple words and his beautiful experiments, his quickness and his clearness, kept the attention, and fixed his instruction in the mind even of the youngest of his hearers, whilst the most practised teacher would find old experiments shown in a new form, which the genius of Faraday only could have invented, and which his handicraft enabled him to carry out." Crookes, too, concluded in connection with the lectures on forces, "The pleasure which all derive from the expositions of Faraday is of a somewhat different kind to that produced by any other philosopher whose lectures we have ever attended. It is partially from the extreme dexterity as an operator. . . All is a sparkling stream of eloquence and experimental illustration. We defy a chemist who loves his science, no matter how often he may himself have repeated an experiment, to feel uninterested when seeing it done by Faraday." He was undoubtedly a rare combination of a masterful lecturer convinced by a wonderful truth, and of a creative scientist sharing his enthusiastic quest with a youthful audience.

Research and self-education

We must consider, therefore, at least briefly, his lecture on "Observations on Mental Education," which was included by him in the final (1859) collection of his reprints.[7] The preface was Faraday's own apology at the age of 67 for its inclusion among these research reports: "These observations were delivered as a lecture before His Royal Highness The Prince Consort and the Members of The Royal Institution on the 6th of May, 1854. They are so immediately connected in their nature and origin with my own experimental life, considered either as cause or consequence, that I have thought the close of this volume not an unfit place for their reproduction." Here is a just recognition of the intimate relation between research and education.

Although this lecture is truly "an intellectual self-portrait,"[8] Faraday's primary concern for self-education included others as well as himself. He began with a broad definition of education: "Education may be understood in so large a sense as to include all that belongs to the improvement of the mind . . . It is necessary that a man *examine himself*, and *that* not carelessly . . . A first result of this habit of mind will be an internal conviction of *ignorance in many things respecting which his neighbors are taught*."

"The first step in correction is to learn our deficiencies . . . self-schooling must continue to the end of his life."

"Consequently, the education which I advocate will require *patience* and *labour* of thought in every exercise tending to improve the judgment."

"I earnestly urge this point of self-education, for I believe it to be more or less the power of every man greatly to improve his judgment." Let us now consider the respective roles of mind, nature and judgment itself in this process of self-criticism.

"A mind so disciplined will be *open to correction upon good grounds in all things*." He cited some of his own beliefs that had later turned out to be mistaken: on the one hand, his incorrect opinion (owing to one of his very few experimental errors) that a spark might result from mere nearness of voltaic metals; on the other hand, his correct insight as to the conduction of

electricity by electrolytes. Faraday insisted, "I hold it as a great point in self-education that the student should be continually engaged in forming exact ideas and expressing them clearly by language." At the same time he emphasized that "the imagination should be taught to present the subject investigated in all possible, and even in impossible views; to search for analogies and likenesses and (if I may say so) of opposition—inverse or contrasted analogies." For example, "we could not reason about electricity without thinking of it as a fluid, or a vibration, or some existent state or form." (He regarded such a model as highly desirable, but not necessary.) Bence Jones commented, "It [imagination] rose sometimes to divination, or scientific second sight, and led him to anticipate results that he or others afterwards proved to be true."

Nature as educator

Faraday expressed a profound belief as to the role of nature: "I am persuaded that all persons may find natural things an admirable school for self-instruction, and a field for the necessary mental exercise; and they may easily apply their habits of thought, thus formed, to a social use; and that they ought to do this, as a duty to themselves and their generation."

"The laws of nature, as we understand them, are the foundation of our knowledge in natural things . . . they have become, as it were, our belief and trust." Recounting the discovery of Neptune, he exclaimed, "What truth, beneath that of revelation, can have an assurance stronger than this?" Later, "If we look to electricity, it, in the hands of the careful investigator, has advanced to the most extraordinary results: it approaches at the motion of the hand, bursts from metal; descends from the atmosphere; surrounds the globe: it talks, it writes, it records, it appears to him (cautious as he learned to become) as a universal spirit in nature."

"The beauty of electricity or of any other force is not that the power is mysterious and unexpected, touching every sense as unawares in turn, but that it is under law, and that the taught intellect can even now govern it largely." In his 1858 Friday discourse on the relation of Sir Charles Wheatstone's electric telegraph to science he argued for science as a sine qua non of education and concluded, "I could give you many illustrations personal to myself. . . *I will simply express my strong belief, that that point of self-education which consists in teaching the mind to resist its desires and inclinations* until they have proved to be right, is the most important of all, not only in things of natural philosophy, but in every department of daily life." Tyndall rightly judged, "Nature, not education rendered Faraday strong and refined."

Later (1862), when appearing before the Public School Commissioners, Faraday argued, "I do think that the study of natural science is so glorious a school for the mind, that with the laws impressed on all created things by the Creator, and the wonderful unity and stability of matter and the forces of matter, there cannot be a better school for the education of the mind." He confessed, "That the natural knowledge which had been given to the world in such abundance through the last fifty years, I may say, should remain untouched, and that no sufficient attempt should be made to convey it to the young mind, growing up and obtaining its first view of these things, is to me a matter so strange that I find it difficult to understand." What would he say about much of science education today?

Judgment and the senses

Finally, in considering the role of judgment one must look directly at the senses themselves. "Our sense-perceptions are wonderful. Even in the observant, but unreflective infant, they soon produce a result which looks like intuition, because of its perfection." On the other hand, Faraday cautioned that "the mind has to be instructed with regard to the senses and their intimations through every step in life."

"Error results occasionally from *believing* our senses; it ought to be considered, rather, as an *error of the judgment* than of the sense." He observed, "to what an extraordinary extent our interpretations of the sense impressions depend upon the experience" (compare the confusing touching of finger tips with hands crossed). "At other times they fail us because we cannot keep a true remembrance of former impressions." Of great importance also is *"the tendency to deceive ourselves regarding all we wish for, and the necessity of resistance to desires."* He recognized that the force of "the temptation which urges us to seek for such evidence and appearances as are in favour of our desires, and to disregard those which oppose them, is wonderfully great" (compare the interesting case of ascertaining whether a ring held by a boy on the end of a long string would swing and, if so, along a straight line or in an oval). He concluded, "A fundamental fact, like an elementary principle, never fails us, its evidence is always true; but on the other hand, we frequently have to ask what is the fact?—often fail in distinguishing it,—and mostly overpass or come short of its true recognition." One must, of course, *"know the conditions* of the matter respecting which we are called upon to make a judgment." Here is Faraday's own credo in this regard: "I believe that the judgment may be educated to a very large extent, and might refer to the fine arts, as giving proof in the affirmative." In this connection, we note Faraday's own enjoyment of music, the opera and the theater.

One popular matter aroused a personal resentment and social concern within him, namely, table turning. He complained, "Shall we educate ourselves in what is known, and then casting away all we have acquired, turn to our ignorance to guide us among the unknown?"

"This law [gravitation] is often cast aside as of no value or authority. . . I will not say they oppose the law though *I have* heard the supposed fact quoted triumphantly against it; but as far as my observation has gone, they will not apply it."

"What can this imply but that society, speaking generally, is not only ignorant as respects education of the judgment, but is also ignorant of its ignorance." He argued, "What has clairvoyance, or mesmerism, or table-rapping done in comparison with results like these [photography]?" He concluded, "I do not object to table-moving, for *itself;* for being once stated, it becomes a fit, though a very unpromising, subject for experiment; but I am opposed to the unwillingness of its advocates to investigate; their boldness to assert; their desire that the reserved and cautious objector should be in error, and I wish, by calling attention to these things, to make the general want of mental discipline and

education manifest." Faraday, moreover, warned that "in respect to the action of magnets on the body, it is almost impossible for an uninstructed person to enter profitably upon such and inquiry."

Astrology is a current illustration of such phenomena that have not been scientifically validated. Despite our growing investments in science education, astrological publications steadily increase; the American Federation of Astrologers (founded at 11:38 a.m. EST, 4 May 1938) has its headquarters in Washington, D. C., and the center of publications is at Tucson in the very neighborhood of the Kitt Peak National Observatory. Together with Bart Bok and Francis J. Heyden, I was recently interested in reviewing the former critical survey of some 25 years ago. The American Astronomical Society, however, showed little interest in such a project; apparently they were frustrated by the overwhelming difficulties inherent in any attempt to combat this mental and social disease. Nevertheless, as was noted by John P. Curran, "eternal vigilance is still the condition for man's liberty."

Faraday himself recognized the value of suspended judgment at times. "When the diffierent data required are in our possession, and we have succeeded in forming a clear idea of each, the mind should be instructed to *balance them one* against another, and not suffered carelessly to hasten to a conclusion."

"As we are not infalliable, so we ought to be cautious." He commended François Arago's reluctance (1824) to interpret the carrying along of a freely suspended magnet about a rotating copper plate as "a most wise and instructive reservation as to his conclusion." Faraday admitted his own uncertainty: "I cannot tell whether there are two fluids [of electricity] or any fluid at all."

He was, nevertheless, convinced that "occasionally and frequently the exercise of the judgment ought to end in *absolute* reservation." He cited a popular instance of "presumptuous judgment": "How frequently has the reported judgment of Davy upon the impossibility of gas-lighting on a large scale been quoted by speculators engaged in tempting monied men into companies." He concluded, "There are many subjects uniting more or less of the most sure and valuable investigations of science with the most imaginary and unprofitable speculation, that are continually passing through various phases of intellectual, experimental, or commercial developments—some to be established, some to disappear, some to recur again and again, like ill weeds that cannot be extirpated, yet can be cultivated to no result or wholesome food for the mind. Such, for instance, in different degrees, are the caloric engine, the electric light . . . mesmerism . . . the perpetual motion," and so forth.

AN 1875 PHOTOGRAPH taken when Faraday was 65 years old. He holds a piece of glass that he made himself, as he did much of his experimental equipment.

A conviction of deficiency

The most significant additional factor in Faraday's own education was undoubtedly his humility; hence its key position in his philosophy of education is not surprising. "This education [mental] has for its first and last step *humility*. It can commence only because of a conviction of deficiency." Faraday's own humility was deeply rooted in his religious convictions.[10] At the start of the lecture on mental education Faraday apologized: "It would be improper here to enter upon this subject [theology] further than to claim an absolute distinction between religious and ordinary belief. I shall be reproached with the weakness of refusing to apply those mental operations which I think good in respect of high things to the very highest. I am content to bear the reproach. Yet,

even in earthly matters, I believe that the invisible things of Him from the creation of the world are clearly seen, being understood by the things that are made, even His eternal power and Godhead; and I have never seen anything incompatible between those things of man which can be known by the spirit of man which is within him, and those things concerning his future, which is within him, and those higher things concerning his future, which he can not know by that spirit." The agnostic Tyndall, indeed, recognized that "the contemplation of Nature, and his own relation to her, produced in Faraday a kind of spiritual exaltation. . . His religious feeling and his philosophy could not be kept apart; there was an habitual overflow of the one into the other."

"Faraday insisted upon the primacy of faith. The world was intelligible, and adapted to the needs of man because God was rational and good."

Just a note about a few of Faraday's comments on formal education. As a member of the Senate of the University of London he had been on a committee to consider the "best method of examination;" he cited his conclusions in a letter to General Portlock of the Royal Military Academy.[1] Faraday insisted that examinations are best when there are written answers, and when viva voce is employed only for supplementing these: "My verbal examinations at the Academy go for little. . . My instructions always have been to look to the note-books for the result." He noted, however: "We think no numerical value can be attached to the questions, because everything depends on how they are answered." He regretted, moreover, that "the cadets have only the lectures, and no practical [laboratory] instruction in chemistry, and yet chemistry is eminently a practical science. [This fact is sometimes overlooked nowadays.] Lectures alone cannot be expected to give more than a general idea of this most extensive range of science." Take heed, modern educators!

Philosophical eulogy

In conclusion, I can do no better than to quote from Jean Baptiste A. Dumas's eulogy of this natural philosopher and teacher par excellence: "In him there appeared to be a natural grace, which made him a teacher full of zeal for the diffusion of the truth, a tireless worker, full of enthusiasm and vivacity in his laboratory, the best and most lovable of men in the bosom of his family, and the most enlightened preacher amongst the humble folk whose faith he followed."[11]

FARADAY AND JOHN TYNDALL. Of Faraday the Irish physicist wrote, ". . . the contemplation of Nature and his own relation to her, produced . . . spiritual exaltation."

References

1. J. Rorie, ed., "Select Exhortations Delivered to Various Churches of Christ by the late Michael Faraday, Wm. Buchanan, John M. Baxter, and Alexander Moir," John Leng, Dundee (1910).
2. H. B. Jones, *The Life and Letters of Faraday*, Longmans, Green, London (1870), vols. 1 and 2.
3. M. Faraday, *Advice to a Lecturer*, The Royal Institution, London, (1960).
4. M. Faraday, *On the Various Forces of Nature*, Thomas Y. Crowell, New York (1961).
5. W. Crookes, ed., *The Chemical History of a Candle by Michael Faraday*, Viking, New York (1960).
6. J. Tyndall, *Faraday as a Discoverer*, D. Appleton, New York (1890).
7. M. Faraday, *Experimental Researches in Chemistry and Physics*, Richard Taylor and William Francis, London (1959).
8. L. P. Williams, *Michael Faraday*, Chapman and Hall, London (1965).
9. B. J. Bok, M. W. Mayall, Scientific Monthly **42**, 233 (1941).
10. R. J. Seeger, Physics **8**, 220 (1966).
11. J. A. Crowther, *The Life and Discoveries of Michael Faraday*, Macmillan, New York (1920). □