the elements of science

eva brann

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Eva Brann

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Editors	George and Meredith Anthony
Associate Editors	Steve Forman Masha Zager
Assistant Editor	Daniel Sullivan
Faculty Advisor	Eva Brann
Cover Design	Gabrielle Bershen

Miss Brann is a tutor at St. John's College, a small liberal arts school, co-educational and non-sectarian, with campuses in Annapolis, Maryland and Santa Fe, New Mexico.

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This article reproduces a lecture given to the upper classes of the Tower Hill School in Wilmington, Delaware on January 31, 1968.

ERRATA SHEET

Page 3, column 1, line 3 ..	change "idesthi" to "idesthai"
Page 7, column 2, line 12 ..	change "mathemetical" to "mathematical"
Page 9, column 2, line 17 ..	change "truest" to "trust"

THE ELEMENTS OF SCIENCE

Eva Brann, Tutor

Students of the Tower Hill School,

The title of my lecture in your lecture series "Revolution and Ferment in Mid-Century" is "The Elements of Science." In it I shall try to say as exactly and plainly as I can what I mean by this title - and this will be what the lecture consists of. I shall use whatever learning or insight I might possess without any reserve for, as you will see, it is part of my argument that these matters, elementary matters, are accessible to all of us insofar as we are human. Presumably you are.

What, then, is the meaning of the word "elements?" Those of you who study Latin may have heard that there is an untrustworthy, but highly suggestive, derivation of this word, according to which it is to be read L-M-N-tum, like alpha-bet or A-B-C, since l, m, n are the first three letters in the second row of the old Latin alphabet of twenty letters. An element is, this derivation implies, a constituent of an abc, in short, a kind of letter.

This understanding of the word implies that to have an elementary knowledge of any subject is to have some sort of reading knowledge of it. And conversely, a subject which has elements is one of which it is possible to acquire a reading knowledge.

Now what is meant by having a reading knowledge

of a subject? An ancient commentator on a certain well-known mathematical work called "The Elements," in discussing its title, says: ". . . the term element is applied by analogy to that which, being one and small, is useful for many purposes." A person, accordingly, who has a reading knowledge, say of books, knows twenty-four small and simple little items which enable him to decipher whole libraries.

You may object that not letters are the true elements of books but something else, something beyond and behind the letters, which the readers should get to as soon as possible - that books should not be read "literally." But this notion, that we should at top speed leap beyond the letter to the general idea and, probably, beyond the poet to his tradition and beyond a paragraph to its cultural background, is extremely dangerous - deadly, in fact.

Let me illustrate what I mean by analyzing a passage from a poet who clearly wants us to pay attention to the text (a text being a woven texture of letter elements) in all its detail, namely a passage from the

Iliad.

The Iliad is the poem of the ferment that takes place in Achilles, a man of such terrific aliveness that he has chosen to expend his life in one short, high-pitched span, rather than to let it wear out quietly and normally. As the time for his death approaches he cannot face the idea of not being alive on this earth, so he shapes his final weeks into an agonizing drama which will drive him inevitably into the death he has, in his heart, chosen. He begins by staying away from the fighting around Troy on a ridiculous pretext and sits singing in his tent. His one close friend, Patroclus, is both ashamed and a little eager to have his own great moment. Achilles allows himself to be persuaded to lend Patroclus his very conspicuous suit of armor, and Patroclus, being mistaken, as is inevitable in Greek armor, for the man whose suit he is wearing, quickly comes under full-scale assault by the Trojans, particularly Hector, their chief, and is killed. He is brought back to Achilles. I shall read what Achilles says in Greek so you can hear the moaning behind his words. "My dear friend is dead," he

says,

> "Pátroklós, ton egó peri pánton tíon hetaíron,
> íson emé kephalé. ton apólesa. teúchea de'Éktor
> déosás apedýse peló ria, thaúma idésthi,
> kála..."

Translated: "My friend is dead, who meant more to me than all my friends, as much as my very self. I have lost him, and Hector who killed him has stripped off the tremendous armor which is a marvelous, a beautiful sight. . . ."

The Greek phrase "ton apolesa" is always translated "I have lost him," but if a reader paid attention to what these words literally say - which would, to be sure, mean learning Greek - he would notice that they have another meaning, one in which the terrific meaning of the whole poem is collected; for what Achilles also, and perhaps primarily, says is: "I have murdered him" - and that is the stark truth.

And futhermore, a careful reader who makes a mental note of the way the loss of the armor to Hector, who will wear it from now on, is emphasized in the whole scene will have a clue for deciphering the climax of the poem. This is the dreamlike chase when Achilles, the fastest of the Greeks, cannot catch his enemy Hector, the heavy-set Trojan, as they keep running around the city caught as in a nightmare, until finally that enemy stops running and turns around. For only such a reader can see in his mind's eye who it is that has finally stopped running and who it is that Achilles is at last facing - himself.

Of course, I am perfectly ready to admit that even this sort of close reading is not a matter of merely reading the letters. But, on the other hand, it is also quite impossible without that kind of beginning, and that is the point I want to make. In any case, I am using "reading knowledge" merely as a metaphor for a certain kind of knowledge of the world, namely elementary knowledge, to which it is analogous. Let me try to say more straightforwardly what seems to me to characterize the realm of the elementary.

If letters are to books as elements are to the

world, it follows that the latter have this character: they must be absolutely simple, limited in kind, but appearing over and over, as often as you please. They must be equally present wherever you turn, and everything must be made "out of" them, though what is made out of them need not be in the least like them, as a word or a paragraph or a book is nothing like a letter. And finally, they must everywhere be combined by similar rules for spelling as it were, by general laws. This elementary simplicity and generality differs from other conceivable kinds of singleness and universality found in intelligible things, for instance from the main idea expressed in a book, since this idea is not necessarily very simple, nor present on every page a hundred times over, nor, for that matter, "in" the book in any literal sense at all. The question is then, whether the world is, in fact, made up of such elements. I might add here a fact which proves nothing but which is at least suggestive, namely that in Greek, a language with an uncanny aptitude for telling the truth, the word for letter and for element in the larger sense is one and the same.

Let us now look at the meaning of the word "science." Those of you who study Latin will know that it is nothing but the Latin word scientia, meaning "knowledge," knowledge in the sense of the ability to distinguish things. The Bible, in its deep understanding of human nature, presents as the first science acquired by man the scientia boni et mali, the knowledge of good and evil, acquired at the price of the loss of paradise. Milton in his poem Paradise Lost gives an interpretation of Chapter 3 of Genesis, where Eve is tempted by the subtle serpent with the fruit of the tree of knowledge and accepts it, which makes it seem as if that episode had been written precisely for this decade. For what, according to Milton, the serpentine Satan in the leaves offers Eve is the fruit of experience, or rather a fruit which induces "experiences" - the experiences which Eve is promised will put her in a state such "that your eyes shall be opened and ye shall be as gods, knowing good and evil." And this is exactly what happens. In a state of intoxication Eve sees the world with great vividness, sees into the center of things, as she

imagines, where at first the beauty and then all the horror of her own human life is revealed to her. The scene ends with Eve, in the aftermath of her high state, squabbling with Adam over matters of life and death. Meanwhile Satan arrives in Hell and reports his initiation of Eve to the experiences of hell, and the fallen angels, for one dreadful moment, turn into hissing serpents who, greedily reaching after that same fruit, chew dust.

This, then, is the original knowledge, a temptation and a sin. But in the seventeenth century, at the beginning of modern times, the world was created over again, sinless this time. On November 10, 1619, a Frenchman named Descartes discovered "an entirely new science," or, as he said, a scientia mirabilis, borrowing a phrase from Psalm 139. (This man, incidentally, had most of his works published by a printer whose emblem was a tree with a serpentine growth on its trunk from which a pagan wise man is deliberately, and with no sinful look about him, plucking a fruit.) He published the foundation of this new science in an account of a series of meditations he had conducted over six days. Presumably he rested on the seventh. His marvelous new science was persuasive enough to come in time to be called by everyone simply "Science."

I mentioned these historical matters only to bring out the blasphemy and arrogance that are, although hidden, always present when we speak of "science," simply. I shall try to show that the "scientists" have no cause for arrogance.

Now what is this "science" simply? I shall illustrate what I think it is with an example taken from a book written by a contemporary of Descartes called Galileo Galilei and entitled, Dialogues Concerning Two New Sciences, and held - imagine - on six successive days. The two new sciences, essentially the same as that founded by Descartes, are those of bodies under pressure and in motion, in short, modern classical physics. "Physics" is a Greek word meaning what belongs to nature. The new knowledge is the science of nature.

I shall illustrate the nature of this natural science with an example chosen from the first of the six successive days of the new creation. Galileo is fascinated by a wonderful coincidence which had been discovered by certain Greek mathematicians: of the tones of our common Western musical scale some, when they are played together as chords, are "concords," that is, they sound well together and are "consonant." Others are dissonant or dicordant. Everyone hears this, and if anyone should claim that he likes dissonance not as a seasoning but by itself, he could only mean that he has gorged on centuries of straight music and is now prepared for a little perversity. Now it turns out that consonant tones can be produced by plucking different strings which have the following remarkable property: all such strings have to each other the relation of one small natural, that is, whole, number to another. Thus the octave, for instance from G to G below, a chord so consonant as to be in an odd way almost an identity, is produced by plucking a string of a basic unit length and another of twice that length. A fifth, as from G down to C, is produced by plucking the string of double length and another of triple the

original unit length. This concord is not quite so smoothly consonant as the octave but, as Galileo says, it tickles the ear and gives "at the same moment the impression of a gentle kiss and of a bite." If now together with the triple string, another string, of four times the unit length, is plucked, we hear the concord of a fourth, from C down to G.

Galileo wants to know why numbers and sensations should show this remarkable coincidence. He observes that plucked strings vibrate and that the number of their vibrations in a given time are dependent on, or as we would say, vary inversely, with the length of the string, which means that the doubly long string vibrates half as often. He further notices that such vibrations can be communicated by the air to other sensitive bodies, for instance a goblet. He also knows that our ears contain a drum which is sensitive in just this way, and he concludes, thereby incidentally founding the science of acoustics, that we hear a satisfying chord when the sympathetic vibrations set up in our ear by two strings are in step or in phase, so that, in the case of the octave, on exactly every second impulse from the shorter, high-

er-sounding string, there comes in a single one from the longer, lower string. But if the vibrations cannot arrive in phase so very often, which will happen if the lengths do not have small number relations (or if perhaps they never arrive together, which must happen, as some of you will know, if it were possible to cut strings which have no unit in common) then the sound is increasingly dissonant and produces an impression from tickling to torturous.

This, it seems to me, is, at least as a beginning, a satisfactory explanation of the phaenomenon, and it is certainly one of the kind called "scientific." What are its characteristics?

You will notice that such an explanation demands that there be certain elements present everywhere - in the strings, in the air, in the ear drum, and that Galileo sees just such elements in numbers and lengths, in arithmetical and geometrical objects. Their presence alone makes such different things as strips of cat's gut and our sensory organs capable of being definitely and precisely related. Such mathematical objects, few and simple in kind, and connected in clearly prescribed ways, are everywhere in nature, and wherever they are, the same general rules apply in such a way that every little occurrence is equally an example of what we call the "laws of nature." This circumstance is responsible for our ability to experiment, since on account of it we can see in a small room on earth the very same laws at work which hold, for instance, our natural satellite, the moon, in its orbit. The science of nature is, accordingly, mathematical science and the elements of nature are mathemetical elements.

What is specially characteristic of mathematical elements? The Greek word "mathematics" means simply "that which is learnable." Why might mathematics have seemed particularly learnable to those who gave it that name (who were, incidentally, identical with those who discovered it)?

You will remember that I compared elements to letters, which are simple and everywhere related by general rules. But we all know that no one can tell

by looking at the twenty-four letters what the rules of spelling are, for letters give no clue to their uses and relations, which are agreed upon arbitrarily. Mathematical elements, on the other hand, do give us such clues; for instance, it is by inspecting a line segment that we know that the whole segment is greater than each of its parts, and it is by thinking about imagined triangles that we know under what circumstances they might be congruent. (I am bypassing here the complicating fact that, having imagined and thought enough about mathematical objects, we may construct a system which pretends that the rules relating numbers to geometric figures came before these objects and that the objects come into being only later, by being constructed according to these rules, or axioms, as they are called.)

Mathematical objects are thus characteristically transparently simple and at the same time rich in built-in relations. This is, I think, why the first mathematical system, Euclid's geometry, was called the "Elements" - geometric objects are, so to speak,

 the perfect elements, elements par excellence, namely simple beginnings whose property it is to enter into a great multitude of things, though these things may in no way appear mathematical, as a consonance does not sound like a small number ratio.

All this implies that to speak of the "elements of science" is as much as to speak of mathematics, which, in turn, is that which everyone can learn. In one of Plato's dialogues, the one called Meno, an experiment is performed by Socrates to show that even a totally uneducated boy, if rightly questioned, can discover within himself the answer to a really rather sophisticated mathematical problem, namely how long a line must be used as the base of a square with an area of two square feet. If there is someone here among you who thinks that he has a particularly hard block against mathematics, I am willing to reproduce this experiment - on the condition that if it works it proves my point, and if it doesn't it proves nothing.

My point is essentially that everyone can learn the elements of science, simply by reason of having a human intellect. The sciences are the pre-eminent

humanities. I may here seem to be turning things upside down, but I shall go right on just the same to make a list which might outrage some of you, a list crudely entitled Easy and Hard Subjects. The easy subjects are: mathematics, particularly Descartes' great discovery of analytic geometry; elementary classical physics and certain approaches to electricity and magnetism as well as to the special theory of relativity; also, I imagine, electronics, computer science, etc. etc. Hard subjects are: the science of the soul, sometimes called psychology; the inquiry into the actions of men, called in the English Greek we so often speak, history (which originally meant "inquiry" simply); the study of men in associations, called sociology; etc., etc. You will notice that my "easy" list consists of the sciences of nature and their prerequisites and applications - and I do, in all seriousness, believe that everyone can learn their beginnings, though I agree that at a certain level they quickly get too complex for the unspecialized student. The "hard" list consists of the study of man, of human beings, and the strange fact is that these are not accessible to any human being by what Descartes called the "unaided light of the intellect," but require something more: a prior knowledge of nature, experience, sensibility and another thing which I will try to describe in a moment. I therefore think my order of difficulty, though it turns the one usually accepted in schools and colleges upside down, is the true one.

I mentioned as one of the requirements of the study of man the knowledge of nature. An obvious reason for this requirement is that we can know little about ourselves unless we know about the things around us which support and oppose us. But there is a deeper and more subtle reason too. In order to understand ourselves we have to know how we come to know, we have to know what it means to have or to do science. And this can never be understood by anyone who has not tried to study the scientific enterprise itself - I myself would never truest a historian who talked of the "Scientific Revolution" and could not talk, for example, about the old and the new ways of generating conic sections. Happily, an elementary knowledge of science is, as I have tried to show, entirely within the power of any high school and college student, pre-

cisely because science rests on elements. And I think that such elementary study - by which I do not mean a survey - is sufficient for the purpose.

That brings me to that other requirement for the study of man. In studying science we build up from the elements to greater complexity and efficacy, and to get there we accept the elements. The beauty of this way is precisely that it gets us somewhere; by it we become powerful experts. Now it seems to me that the ultimate requirement for the study of man is a firm unwillingness to be stampeded along this road. To know ourselves it is necessary to turn around, to turn on, and not away from, the elements, in the Latin term, to reflect. This kind of patient reflection will not immediately teach us how to do things, but it is indispensable if we want to know what we are doing and why. In other words, this last requirement for the study of man is identical with the chief requirement for purposeful action.

The word for turning things around or upside
 down is "revolution." The planets in their courses are at the moment making revolutions. If somebody gets upset and in turn upsets a car, there has been a revolution, and when a man suddenly flips and stands on his head, literally or metaphorically, he has undergone a revolution. All such revolutions, tremendous as they may seem, are explicable in terms of the laws of nature. They occur as do things which are always the same, in mid-century, at the beginning, or at the end, and the less we attend to current events in studying them, the more hope we shall have of understanding them. But there is another kind of revolution, a revolution which is an action in the true sense of the word, not a mere happening. It occurs wherever someone turns a matter over in his mind and, all by and for himself, comes to a conclusion which may be - though it need not be - utterly the opposite of what the others think they think. It is the possibility of such truly tremendous revolutions which I was really leading up to tonight, and if there are students here who think that any other revolutions should concern them much at this point in their lives, I wish they would tell me their reasons later on.

Thank you.