NEWTONIAN PHYSICS AND AVIATION CADETS

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The Teaching of Physics

The following is an account of some difficulties I encountered while teaching elementary classical (newtonian) physics to aviation cadets at the beginning of the war. It is most likely that the same difficulties are encountered by very many teachers. Not very long ago an attitude prevailed among many educators and the public that most young people are 'naturally' hostile to mathematics and the exact sciences; that these disciplines are a 'necessary evil' like Latin, included in the curricula because they had always been included and therefore 'necessary' but of little or no 'practical value.' This attitude and the lack of understanding of the difficulties made it difficult to combat them.

At present there is an ever increasing realization that the knowledge of arithmetic, algebra, and elementary physics is indispensable to many people who participate in activities connected with our technology. What is not yet quite realized is that the educational value of the *process* of acquiring this elementary knowledge is even more valuable than the knowledge itself, because this process tends to shape mentalities able to utilize our technology most efficiently. This process, moreover, is a form of mental hygiene, beneficial for what Korzybski calls 'an efficient exploitation of our nervous systems.' It is to be noted that our nervous systems must also be considered as a part of our modern technology. At any rate, the aviation cadet must acquire this knowledge or be eliminated. Thus the difficulties which arise during the attempts to impart these very elementary disciplines to young men in their early twenties become very important.

An attempt will be made to analyze the difficulties and to show them to be mostly of verbal origin.

What 'Makes' It Fall

A great deal is said about the applications of new mathematics and physics (the theory of relativity, quantum mechanics, non-euclidean geometries). It is often remarked that these phases of the sciences are difficult to understand because they are 'contrary to experience' or 'detached from experience.' It is the purpose here to show that probably 'experience' has little to do with the ease or difficulty of understanding new formulations, except the experience in the use of words. This will be shown in the analysis of the strong resistance offered by the cadets in absorbing *newtonian* formulations, although it is generally said that newtonian physics, along with euclidean geometry and that part of algebra which does deal

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with imaginaries and hypercomplex quantities is *not* contrary to experience, but on the contrary is supposed to have resulted from deeply seated 'intuitions,' which, in turn, are rooted in experience.

The formulations of physics in the order of their presentation were the following: 1. The Second Law of Motion (Newton); 2. The Third Law of Motion (Newton); 3. Centripetal and Centrifugal Forces; 4. Bernoulli's Principle (Hydrodynamics); 5. Boyle's Law (Perfect Gas).

The resistance to these formulations became apparent in the answers to the questions in our quizzes and examinations. Invariably, after working a great many problems involving the equation

$$F = ma,$$

the cadets were asked the following questions on a quiz:

> When a parachutist reaches his terminal velocity in falling, he is moving toward the ground with constant speed. At that time:
>
> 1. the downward force acting on the parachutist is greater than the upward force;
> 2. the upward force is greater than the downward force;
> 3. both forces are of equal magnitude. (Multiple choice answer)

As I recall, about 75% of the cadets underlined the first choice, and the remainder answered the question correctly. When confronted with the correct answer, the immediate objection was usually: 'If the upward force equals the downward force, what makes the parachutist fall?'

The worst obstacle to overcome is the difficulty associated with the verb 'make.' What *makes* things fall? In other words what is the agency assumed to possess a 'will,' a 'power' to make things happen? The entire anthropomorphic attitude toward natural phenomena, remnant of ancient magic, is contained in this formulation of the question, 'What *makes* it so?' The very first inquiries of children into observed phenomena are so formulated as to inhibit correct thinking. Moreover, these inquiries are actively encouraged by well-meaning parents and teachers who rejoice at this evidence of alertness and curiosity, and do not realize that such formulation of questions may eventually do more harm than good by giving rise to prejudices difficult to overcome in later years.

Let us return to the example at hand and illustrate two types of reasoning. One of these is correct within the realm of the problem and leads to the correct answer; the other is incorrect and leads to a wrong answer.

It should be the effort of educators to encourage the following formulation and solution of this simple problem.

GIVEN: a body moves with constant velocity v toward the earth and is acted upon by the force of gravity (downward) and the force of air resistance (upward).

TO DETERMINE: The relative magnitude of two forces.

SOLUTION: First determine the acceleration of the body. By definition, the acceleration $a = dv/dt$; hence $a = O$, since v is a constant by hypothesis. (In case differentiation is not known, an algebraic definition of average acceleration gives the same result). If F is the force acting on a body, (the body is here considered as a particle), m the mass, a the acceleration in the direction of the force, then by Newton's Second Law, $F = ma$. Since $a = O$, we have $F = m \times O = O$. But $F = F_1 - F_2$, where F_1 and F_2 are the respective magnitudes of the downward and upward forces acting on the body. Hence $F_1 - F_2 = O$; $F_1 = F_2$.

INTERPRETATION OF RESULT: The downward and upward forces are equal. Period.

There is no room for the question 'What makes it go?' Of course the same result could be derived by a shorter verbal argument based on Newton's First Law, but in my opinion verbal arguments should be avoided as much as possible. Sometimes they lead to disastrous results. They will lead to correct results if they are faithful translations into English of mathematics. But in most cases the language of mathematics is shorter and more elegant than the clumsy verbal translations.

Let us now see the steps in the 'reasoning' or rather in the chain of verbal reactions which go on in the minds of the young men who are *not* taught to mathematicise. Such 'reasoning' might well have been included in Aristotle's treatment of the subject.

> 'What makes bodies fall? Gravity. If it were not for gravity, bodies would not fall. There is an upward force acting on the body. This force resists gravity. If it were as strong as the force of gravity, it would cancel it. Body would not fall. Nevertheless body is falling. Therefore the resisting force is not strong enough to overcome gravity.'

That this is the actual chain of 'reasoning' in the minds of mathematically untrained people was brought out in discussion, and the author remembers very well when he indulged such 'reasoning' himself.

Notice the implications. Something *makes* bodies fall. There is close connection between this 'making' bodies fall or in general 'making' things happen and one's own sensations of 'willing,' which one unconsciously and tacitly attributes to 'nature's agents.' It is not a very great step from demons to 'gravity,' 'electricity,' etc. Nor is the step very significant, if the 'reasoning' remains basically the same.

The Little Boy and the Wagon

This situation is illustrated even more strikingly in the following problem based on Newton's Third Law.

> Horse A and Horse B pull on the same rope in opposite directions with forces of equal magnitude. Horse C pulls on a rope tied to a tree with the same force as Horse A and Horse B pull on their rope. Compare the tensions in the two ropes.

If Newton's Third Law is applied in this case, the correct answer, namely that the tensions are equal, is immediately obtained. But the usual verbal reaction is, 'But Horse C pulls *alone* on its rope, while Horse B is *helping* Horse A to create more tension.'

Again the word 'pull' give animistic connotations to the term 'force.' When one mentions the fact that the tree also 'exerts' a force, animistically oriented students agree only half-heartedly: 'Yes, I suppose so, but the tree doesn't *pull.* A horse *pulls.*'

How much confusion could be spared if educators prohibited the consideration of forces as exerted *by* agents or objects and talked exclusively of forces acting *on* bodies, the only forces of statics and dynamics that matter. Then of necessity such problems of mechanics would reduce to strictly mathematical interpretations in terms of vector diagrams and vector equations.

The statement encountered in the Second Reader, 'The Little Boy pulls the wagon,' deals not with newtonian mechanics but with the Little Boy's inner reactions. It has to do with the Little Boy's desires for the wagon to behave in a certain way. Only because this inner state may exist independently of the behavior or even of the existence of the wagon, can we speak of the Little Boy as a *cause,* which 'makes' the wagon move. In the picture which excludes the Little Boy's inner state, there is nothing which makes him the 'cause' and the movement of the wagon the 'effect.' Because to the force that is exerted on the wagon 'by' the Little Boy, there is a force exerted on the Little Boy 'by' the wagon. The force of friction 'by' the earth enabling the Little Boy to move is also imparted to the earth resulting in actual acceleration of the earth relative to the wagon and to the stars. In the physical picture there is no 'agency.' There is only *a state of affairs,* which alone should be the object of investigation. In such a light all metaphysical imperatives about the 'First Cause' become meaningless.

Good Gremlins and Bad Gremlins

The next principle, involving very similar difficulties, deals with centripetal and centrifugal forces. A simple derivation based on Newton's Second Law and Euclidean geometry shows that a particle moving along a circle is acted upon by a force whose magnitude is

$$F = mV^2/R$$

and which is directed toward the center of the circle. V is the magnitude of the linear velocity of the particle, and R the radius of the circle. Thus the body (particle) is never in equilibrium. It is always being accelerated toward the center of the circle. This acceleration is a function of the force acting on it. We have

$$a = F/m = V^2/R$$

Similarly the force is a function of the acceleration:

$$F = ma = mV^2/R.$$

It is not fruitful to speak of a force 'causing' the body to move in a circle. The motion of the body may well be the 'cause' of the force. Mathematically the kindest thing that can be said about the terms 'cause' and 'effect' is that they can be taken as synonyms for 'independent' and 'dependent' variables, and if the equation allows one of the variables to be considered independent, then necessarily, either physical term may be treated as a 'cause.'

Not so, however, in the animistic thought. According to this 'reasoning,' the centripetal force 'makes' the body go in a circle, and the preposterously common misinterpretation of Newton's Third Law, coupled with the feeling of 'pull' on one's hand when an object is twirled on a string, at once creates a 'centrifugal force,' which 'opposes' the 'centripetal force' and tries to 'make' the body fly out away from the center. In one of the popular treatises on the physics of flight circulating among the cadets, I came on the following statement, which I do not remember *verbatim,* but whose gist I reproduce faithfully.

> 'When a plane is turning around a circle, two forces are acting on it, the centripetal, directed toward the center of the circle, and the centrifugal, directed away from the center. If the radius of the circle is too small for the speed, the centrifugal force may become greater than the centripetal, making the plane swerve out of the circle. It is wrong, however, to suppose that the centripetal force ever stops acting. The two always go together. It is when the centrifugal force overcomes the centripetal that the plane begins to swerve.'

Substitute 'good gremlins' and 'bad gremlins' for centripetal and centrifugal forces respectively, and you have a 1944 demonology.

The astonishing prevalence of the centrifugal force superstition is brought out in a conversation with practically every non-mathematicising adult, who is somewhat 'acquainted' with the first principles of newtonian mechanics. It is very easy to bring him to a contradiction by just letting him explain the mechanics of circular motion. Sometimes he will grasp the words of Newton's Third Law and state that centripetal and centrifugal forces are always equal and oppositely directed, but he tacitly assumes them both to be acting on the same body. This mistake has its roots in the powerful *verbal* resistance to the idea that a body may accelerate toward a point in space *while remaining at the same distance from the point. The resistance results from the tyranny of the word 'toward' which is associated with diminishing distance. Thus* he unconsciously rejects the fact that a body moving along a circle is accelerating constantly toward the center. This in turn leads to the tacit assumption that the forces on the body are 'balanced' and to the mistaken notion about the facts of centrifugal force. But of course the balance of forces contradicts Newton's First Law. When this contradiction is pointed out, the non-mathematicising adult begins to construct fantasies about the 'struggle' between centripetal and centrifugal forces and gets entirely lost in a metaphysical mire.

'Everything is all right,' the 'popular' book on aeronautics assures the gullible cadet, 'as long as the two forces are balanced, but the moment the centrifugal force becomes too great, the plane will swerve.'

The use of scientific terms makes this 'physics' no more scientific than the use of 'scientific terms' makes astrology scientific. The 'physics' presented in these popular 'non-technical, non-mathematical' treatises really is an account of animistic wish reactions. We wish to make a plane follow a circular path; so we turn the rudder (magic), thus telling the plane what to do, and the plane 'obeys.' Now if everything is 'all right,' i.e. the 'forces' are 'balanced' (note the connotation of 'balance' with general well-being applied to the particular case of a plane moving in the *desired* path), the plane will continue to move as we wish, but the moment the 'balance' is disturbed, the plane begins to misbehave, etc., etc.

How many readers, delighting in explaining the universe to inquiring children (really few occupations are more delightful), proudly tell them that 'centrifugal force keeps the water from spilling from the bucket, if one twirls it in a vertical circle'? They may as well tell them it is Santa Claus. True, centrifugal force is a very much more useful term than Santa Claus, but the properties attributed to it in the case of the twirling bucket are simply not true.

The entire wording of the question 'What makes it so?' or 'What prevents it from doing thus?' is based on false animistic or anthropomorphic assumptions implicit in the structure of everyday language. Each repetition of such questions, and of 'answers' based upon them, strengthens these animistic assumptions and makes the full development of one's ability to absorb knowledge increasingly difficult. The widely prevalent distaste for mathematics and other comparatively exact sciences may well have its roots in this attitude.

The question, 'Why does not water spill from a twirling bucket, when it is upside down?' should be answered by such an analysis as the following:

COUNTERQUESTION: What do you expect the water to do?

PROBABLE ANSWER: I expect it to spill.

Q. Why?
A. When the bucket is upside down, there is nothing to prevent it from falling to the ground.
Q. By 'falling' do you mean moving toward the ground?
A. Yes.
Q. Why should a falling object move toward the ground?
A. I have just defined 'falling' so.
Q. What causes falling?
A. Gravity.
Q. Then, since you consider 'falling' and 'moving toward the ground' synonymous, you conclude that any object under influence of gravity alone must move toward the ground?
A. Yes.
Q. But is this true? Does the moon move toward the ground? Does a stone which you have just thrown upward? Yet both are predominantly under the influence of earth's gravity.

At this point we have supposedly shaken the animistic notion of gravity which pictures 'Mother Earth' calling, 'Come to me, my children,' 'making' all things move toward it unless opposed by other 'forces,' like the 'centrifugal force' or 'inertia,' which people confuse with force. I think it is possible to explain to a child who is mature enough to be interested in such things that a stone thrown upward is also 'falling' even while moving upward, if falling is explained to mean any motion of a body acted upon by the earth's gravity alone. (We are really equating falling with acceleration.) This generalized falling would include paths of all projectiles in vacuum, the path of the moon (neglecting the sun's gravitational field), and many other events not ordinarily regarded as 'falling.' This explanation will also help destroy some verbally acquired notions about the behavior of a stone thrown upward. These notions as held by non-mathematicising adults usually tacitly attribute animistic qualities to the stone. The unconscious or semi-conscious verbal process goes as follows:

'I threw the stone on its way. It flew up, because I threw it up (*i.e.* wanted it to go up). As it leaves my hand, it is still under my influence. (More sophisticated people rationalize this magic as "inertia"). But bye and bye the inertia (read magic) wears off, and the stone becomes more and more influenced by the "opposing force" of gravity, which finally takes the upper hand, and the stone begins to fall.'

The mathematicizing physicist on the other hand considers the stone a freely falling body (barring air resistance) the instant it leaves the hand that threw it. The path of the stone can be quite accurately predicted under these assumptions, the discrepancies being reduced as more and more refined corrections are introduced. We consider the mathematical theory of falling bodies 'truer' than the verbal explanation above, because of the relativistic and quantitative definition of 'truth.' To put it roughly, one theory is truer than another if it assumes less and explains (predicts) more. So far the truest of all scientific theories have been the mathematically formulated ones.

In my opinion, explaining to the child the phenomenon of the whirling bucket becomes possible only when the child is able to comprehend the equation that describes it. But it is possible to impart the critical notion that 'falling' does not necessarily mean 'moving toward the ground,' and that bodies do not necessarily move toward the ground even if there is nothing to oppose such motion.

When mathematicizing becomes sufficiently advanced, the term *acceleration* should be brought up immediately and connected functionally with force in Newton's Second Law. The difference between velocity and acceleration should be constantly emphasized. After the algebraic equation for the centripetal force has been derived, the 'explanation' of the behavior of the water in the whirling bucket should involve the examination of facts and the comparison of these facts with the equation. At the instant when the bucket is in the upside down position there are two forces acting on the water: (1) the force of gravity, equal in magnitude to the weight of the water and directed *downward,* and (2) the force transmitted by the tension of the string and the bottom of the bucket, *also directed downward* (which the believers in the 'centrifugal force' fairy tale will find especially astonishing). There is no upward force at all! Since the two forces are in the same direction, their resultant is simply their sum and equals the total force on the water directed *toward the center of the circle* along which the bucket is moving. (Note that we are considering the instant when the bucket is at the top of the circle.) We now have the force acting on the body which moves in a circular path. According to Newton's mechanics, this force should equal the mass of the body multiplied by the square of its linear velocity divided by the radius of the circle, which it does. *Nothing further need be said.* The phenomenon is explained, since the elements of behavior when translated into mathematical terms satisfy the equation which predicts the behavior. All other considerations are irrelevant.

Thus it appears that the popular belief in this case is not only not in accordance with the facts but actually contrary to fact. Popular belief states that a force opposing gravity, *i.e.,* an upward force, is acting on the water when the bucket is in upside down position, when as a matter of fact, the examination of the forces in action from the point of view of an observer stationary relative to the earth shows that the only other force besides gravity acting on the water is an additional *downward* force (transmitted by the tension of the string). We shall see below that the postulation of 'centrifugal forces' is permissible but only when a different point of view (coördinate system) is chosen, but such postulation really complicates matters instead of simplying them, and the ignorance of underlying assumptions always causes confusion.

'Bottlenecks'

The next example deals with Bernoulli's principle of hydrodynamics. This principle was explained to the cadets in connection with the theory of flight based on streamlined airfoils and in connection with the action of carburetors and Venturi tubes.

Stated in qualitative terms, the Bernoulli principle of hydrodynamics implies that under conditions of steady flow, if the cross-section of the stream tube decreases, then the velocity of flow increases, and the pressure within the stream tube decreases. This last statement is evident from the equation

$$p + d V^2/2 = C$$

where p is the pressure at a given point in the stream tube, d the density of the liquid and V the velocity of flow. The equation is derived directly from the assumption of conservation of energy, the definition of pressure, and the assumption of the incompressibility of the liquid. It is within certain limits a good approximation of observed facts.

The cadets were reluctant to accept the fact that the velocity of flow actually increases in the narrower sections of the channel (they were thinking of Sunday evening traffic jams in the narrow sections of the road and of the expression 'bottle neck'). They positively rebelled at the idea of decreased pressure. Again the analysis of the difficulty points to verbal prejudices and animistic assumptions. The main associations with the word 'pressure' is the expression 'restriction of liberty.' Hence the totally mistaken notion that pressure within the liquid must increase as it is 'forced' into a narrower channel. Again the technique was applied of analysing the verbal associations and pointing out the seat of the delusion. At this stage (fairly far in the course) the breaking down of false ideas was considerably easier.

In Boyle's law, the animistic 'cause and effect' became especially obvious. On one of the quizzes I proposed the following question:

> Other things being equal, when the pressure on the walls of a cylinder containing a quantity of gas increases, the volume of the cylinder (considered flexible) (1) increases, (2) decreases, (3) remains the same.

After disastrous results, many of my colleagues argued that this was a 'trick question,' but some agreed with me that I was bringing out an important point and phrasing the question in such a way that mathematicizing would give the correct answer, while the animistic approach would lead to a wrong one. In answering the question mathematically, one writes down the equation

$$PV = C,$$

where P is the pressure and V the volume of a quantity of gas, while C is a constant. From this formula it is at once evident that whenever P increases, V decreases, and vice versa.

Animistic reasoning goes approximately as follows:

'The gas *wants* to expand. This tendency to expand is evident in the pressure the gas exerts on the walls of its container. The more pressure, the greater the tendency to expand. Hence the greater will be the volume.'

Those of my colleagues who objected to my wording said that the question should have read 'When the pressure *on* a quantity of gas increases, its volume, etc.' But note how this wording invites the derivation of the correct answer by another animistic assumption:

'When I exert pressure on a gas, I am compressing it; hence the volume decreases.'

Why talk at all about difference between the pressure on the walls and the pressure on the gas? The two are connected by the equality sign in Newton's Third Law. Neither is conceivable without the other. The reason I worded the problem as I did was precisely an attempt to avoid the animistic 'cause and effect' notion, where the 'cause' is a conscious agency and the 'effect' is the passive obedience of the object. I wished to emphasize a functional relationship between two mathematical quantities instead of attributing to them 'wills' camouflaged by the obscure term 'tendency.'

Shifting Frames of Reference

In closing I want to take an example of extremely obscure treatment given in 'college texts' to some physical phenomena. This treatment conceals preposterous shifts of meaning, definition, and assumptions, which when consciously applied are usually called sophistry. The training of cadets in scientific thought in order to mold mentalities able to deal most efficiently with technology is only a special case of the general necessity of training the entire new generation and generations to come in scientific thinking. Once more I choose the treatment of 'centrifugal force,' that scapegoat of the inability or disinclination to mathematicize. Again and again one encounters in 'college texts' the statement that the weight of an object is the resultant of the 'pull of gravity' and an opposing force, the centrifugal force, 'due to the earth's rotation.'

This is a common explanation. Any believer in centrifugal force will say that it makes an object weigh less at the equator than near the poles, because the earth rotates faster at the equator. When pressed further, this believer will admit that what he is actually measuring when he is weighing an object on a spring balance is the tension of the spring. The fallacious reasoning then does its deadly work as follows:

'The tension of the spring is less at the equator than at the pole (observed fact). But the body weighed is at rest with respect to the earth in both cases. Therefore the tension of the spring equals the downward force acting on the body in both cases. But the body is equidistant from the center in both cases (the earth is assumed to be spherical and homogeneous). Hence the force of gravity acting on it must be the same in both cases according to the inverse square law of Newton. Therefore there must be an opposing force at the equator not present at the pole. This force is due to the earth's rotation, the centrifugal force, since it is directed away from the center of the earth.'

The above reasoning is riddled with contradictions. It presumes to argue on the basis of Newton's laws of motion and the law of gravity, but it rests on two contradictory assumptions, namely, that the earth is not rotating and that the earth is rotating (*i.e.,* the frame of reference shifts from one relative to which the earth is not rotating to one relative to which the earth is rotating).

To show this, note that Newton's formulation of the laws of motion and the law of gravity contains a tacit assumption, *not* explicitly stated, namely, that a system of coördinates relative to which all motion is to be considered *has been chosen.* Actually Newton chose his coördinate system somewhere at a fixed star. It does not matter which. The motion of the stars with respect to each other may be considered as non-accelerating, so that the transformation of coördinate system from one star to another leaves the laws invariant within the limits of their precision. Nor does the transformation of coördinates to an accelerated system such as the rotating earth affect the first two laws of motion, in which force is treated as a function of acceleration and therefore is a relative concept, depending on the coördinate system chosen. However, the transformation of coördinates to an accelerated system such as the rotating earth does significantly affect Newton's Third Law and the law of gravity, because in the formulation of these laws force is *not* a function of acceleration! So that any reasoning which involves the assumption of a stationary earth cannot also assume the validity of either Newton's Third Law or the inverse square law of gravity without assuming additional corrections. But the centrifugal force argument does assume a stationary earth in that the body weighed at the equator is considered at rest relative to the 'earth.' The phrase 'at rest relative to the earth' has no meaning if a rotating earth is assumed, because a body at rest relative to the surface of the earth is not at rest relative to the center, since every point on the surface suffers an acceleration toward the center. But the argument above first considers the earth stationary, then proceeds to conclude the existence of a force due 'to the rotation of the earth.'

It is, of course, possible to make either assumption, but one must swallow the consequences. Let us begin with the assumption of a rotating earth, *i.e.*, let us say our frame of reference is Sirius. In this case the inverse square law is valid, but the object weighed is not at rest relative to the center of the earth. It suffers an acceleration. Therefore the forces on that object are not balanced; the downward force of gravity is greater than the upward tension of the spring, and the phenomenon is explained. It is, of course, immaterial whether we define the 'weight' of the object the tension of the spring or the pull of gravity. We were primarily interested in explaining the difference in the tensions of a spring balance at the pole and at the equator. Note that no 'centrifugal force' enters the argument.

Now let us proceed on the other assumption, namely, that the earth *is* stationary, *i.e.*, our frame of reference is at the earth with the origin at the center and the axes through particular points on the surface. If this assumption is made, the inverse square law is no longer valid, because it is not invariant under the transformation of coördinates to accelerated systems. One could still assume the inverse square law and *correct* it by introducing a force throughout the universe which would correct it. This force would behave at the surface of the earth as the abovementioned centrifugal force. Consequently, the hypothesis of 'centrifugal force' may enter the argument only if the earth is assumed *not* to rotate. How then is the centrifugal force considered as being 'due to the earth's rotation'? Rather the following explanation would have some justification: 'I have to introduce "centrifugal force" when I shift my hypothesis from a stationary earth (when I consider the object weighed at rest relative to the center) to a rotating earth (when I assume the validity of the inverse square law) and am not aware of what I am doing.'

This patches up the 'centrifugal force' explanation of the loss of weight at the equator. But is it simple? Is it elegant? Is it valuable? Is it healthy? Why not mathematicize instead? Why not state one's postulates explicitly and in advance as demanded by scientific honesty? There is a whole world of phenomena to be satisfactorily explained by newtonian physics and euclidean geometry without recourse to more advanced ideas of relativity theories, if one is careful in the translation from mathematical language (on which physics and geometry are rigorously based) to our sloppy ordinary languages.

Just one more word about the verbal difficulties of the last problem. If a rotating earth is assumed (the simplest assumption, if the problem is to be treated by newtonian theory), the verbal answers to the question about the difference in weight of an object at the pole and at the equator would run thus:

QUESTION: Why does this object weigh less in Peru than in Alaska?

ANSWER: What do you mean by 'weight'?

Q. The force of gravity acting on the object.

A. It is not less; it is the same.

Q. Why then is the tension of the spring balance less?

A. In Peru the tension of the spring balance is actually less than the force of gravity.

Q. Why?

A. Because in Peru the object is accelerating toward the center of the earth more than in Alaska. Actually in Alaska there is also a difference between the weight and the tension, but this difference is smaller, because the acceleration is smaller. Only at the pole is the object at rest relative to the center of the earth and the two forces are equal.

Note that the gist of the dialogue is this:

QUESTION: Why are the forces on the object not balanced?
ANSWER: Because the object is accelerated.

The usual animistic interpretation of force demands the reversal of this 'why' and 'because.' According to this interpretation the answer is perfectly understandable if the question reads, 'Why is the object accelerated?' and the answer is 'Because the forces are not balanced.' This, you see, is proper. Force is a *cause;* acceleration the *effect.* The unfortunate formulation of Newton's First Law (or its wrong interpretation) in which uniform linear motion is implied to be 'natural' and forces are treated as disturbing influences, *causes,* has done a great deal of harm in strengthening the cause-effect delusion. Its roots are deep in theology and demonology. It appears that an important problem of education is to deal this delusion decisive blows and to prevent its domination of our semantic reactions.

The importance placed by the Air Training Command on the preparation of future flyers in scientific thinking habits is reflected in the emphasis placed on mathematics and physics courses in their training program. The actual value of scientific thinking in a person engaged in combat is, of course, almost impossible to evaluate, because of the absence of controled observable data. We can only surmise that such training is valuable by analogy with the industrial field, and by noting that all purposeful human activity depends on organization and on the sanity of the individuals engaged in it.

The cadet has a perfect right to ask, 'Do I have to know this to handle a stick?' No arrogant answer about 'knowledge for the sake of knowledge' which some university professors from the time of Euclid have indulged in, is justified here, for the cadets are trained for one thing only—to defeat the enemy in the air and from the air, and any effort which is not somehow connected with this end is wasteful. It is only later, when overseas I had the pleasure of observing some of the students we had taught, that I began to believe what I had told the cadets when I used to teach them, that winning the war was not just 'handling the stick,' and that the few ideas about the value of mathematicizing that we tried to impart into those young men who passed through our classrooms at Maxwell Field, meager as they were, were nonetheless valuable if successfully absorbed in enabling the nervous systems of $Smith_1$, $Smith_2$, etc., to resist the poison being generated by the nervous systems of $Schulz_1$, $Schulz_2$, etc.

To what final conclusions are we then led respecting the nature and extent of the scholastic logic? I think to the following: that it is not a science, but a collection of scientific truths, too incomplete to form a system of themselves, and not sufficiently fundamental to serve as the foundation upon which a perfect system may rest.

GEORGE BOOLE, *Investigation of the Laws of Thought*