Teleology in Science Teaching

Professors and textbooks alike make uncritical use of teleological and anthropomorphic language.

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Each of us is for good and against evil. For most teachers of science, teleology and anthropomorphism are not issues to be debated but to be deplored —we stand against the evil. In keeping with this attitude, I shall not here debate with any who may have philosophical convictions in favor of teleology; their concept of the good differs from mine. I do intend to challenge those of us who argue against teleology but permit it to appear in our own lectures and ignore it in assigned readings.

If science is taught as a body of information, if a science course earns that ever-to-be-prized encomium, "a course with plenty of meat and a hard, solid core of facts," then a certain indifference to frills such as rigorous exclusion of teleology is not surprising, and an obliviousness to imprecise language must be expected. On the other hand, "lightweight" courses, courses designed to meet liberal-arts objectives through an examination of science as an intellectual discipline or through study of scientific attitudes and methods, are likely to contain at least *some* explicit treatment of these "evils," together with some examples of objectionable phraseology which the student (but not the instructor?) is expected to avoid. When teleological, animistic, or anthropomorphic expressions escape notice in the latter type of course, we should perhaps shrug philosophically and admit that we cannot expect the same perfection in professors that we demand in students. Nevertheless, whatever the approach to science teaching, careless language seems inconsistent with our pious declarations against "evil." Evidences of careless language are not hard to find in texts, and a random selection to substantiate this point is quoted below. They may be even more common in lectures, although this is more difficult to document since one has so little occasion to listen to his colleagues' lectures and one's own lectures are without blemish! Quiz questions are also likely to be "contaminated"—probably the most unkind cut of all to students. In short, it appears that, despite our almost unanimous disapproval of teleology and anthropomorphism, they are far from lacking in our instructional material and, I will argue, far from absent from our thinking.

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The Usual Excuses

Before reading the evidence, perhaps we should review some of the reasons given by authors and lecturers for their lapses into teleological and similarly "unscientific" language. Commonly, these reasons are accompanied by disclaimers of "evil" intent.

First, there is the argument that the objectionable phraseology is used only to avoid "awkward circumlocution" or "tiresome periphrasis." At least in some instances it can be shown that greater rigor can be achieved without awkwardness, and it is debatable whether rigor should be subordinated to simplicity.

Second, the claim is often made that the objection is purely a semantic one, a mere quibble, and that the words under consideration are as suitable as any others. Here we can only counter with the army claim that "if an order *can* be misunderstood, it *will* be misunderstood." Too often an acrimonious dialogue ensues from which it emerges that "I am more rigorous than thou."

Third, we hear the excuse that vivid writing or intimate lecturing may justifiably sacrifice rigor in the interests of more effective rapport. Since greater rapport is presumed to increase learning, we have the paradox that the students are learning best that which we do not want them to learn.

Fourth, quiz questions, especially on objective quizzes, are said to require directness and brevity; they are to be questions on course material rather than on ability to read rapidly, and therefore brief teleological or anthropomorphic phrases may be excused "so long as the students know what is required." This interesting philosophy seems to maintain that grades may depend upon students' acceptance of terminology that the professor would condemn if it came from a student. There is also something pernicious in the attitude that rigor is a luxury we cannot afford when something so important as a quiz is in the balance.

Examples of Nonrigorous Language

With these excuses in mind (and no doubt others can be adduced), let us look at examples taken from texts and books of the sort recommended for collateral reading. That the majority of the examples come from books on biology should give little comfort to physical scientists, inasmuch as more biology books than others were conveniently at hand. Even without a thorough inspection, examples were found in every book examined, whether the subject was biology, chemistry, physics, astronomy, or geology. The quoted examples by no means include all those which were noted.

Rather uncommon are the explicit statements of goal or purpose, perhaps because such statements are not inadvertent but represent a deliberate attempt to produce some (undiscerned) effect:

"It [the universe] emerged full-armed, as it were, out of nothing, apparently for the sole purpose of blazing its way to an eternal death" (*1*, p. 26).

"The structures named in quotation marks [root, stems, leaves of stoneworts] are not anatomically like the true roots, stems, leaves and seeds of higher plants, but they do serve similar purposes and show a remarkable degree of differentiation for an alga" (*2*, p. 498).

"Most green algae produce flagellated or amoeboid reproductive cells whose special purpose is to function as gametes" (*3*, p. 22).

"One purpose of food is to act as a

fuel for our bodies, supplying us with heat and muscular energy" (*4*, p. 384).

"Whatever the valley shapes produced in various stages of landscape development, whatever different kinds of rock may be present, the ultimate goal of stream erosion is to reduce the land surface to a nearly flat plain approximately at sea level" (*4*, p. 510).

Beware the infinitive form of the verb. In each of the last three quotations it is intimately involved with outright teleology. In more subtle contexts it is the most common producer of teleological implication. From the above statements of "goal . . . is to reduce" or "purpose is to function," we can continue with a graded series of quotations arranged to show that, regrettably often, *to* is merely an abbreviation of *in order to*:

"Very little is known concerning these forces, except that they must be considerable in order to overcome the normal repulsion between the positively charged particles in the nucleus" (*5*).

"In combining with other atoms, the atoms of an element *strive to attain the stable arrangement of electrons that characterizes the inert atoms of the elements of Group 0*" [italics in the original] (*6*).

"Seeds are modified to function as agents in the distribution of the species" (*7*, p. 520).

"Sand grains, pebbles, and boulders are the tools which a stream uses to dig into its bed" (*4*, p. 503).

"The ammonia molecule can attach a proton to itself, to form an ammonium ion, NH_4^+ . . ." (*8*, p. 237).

"In this form, each [helix of DNA] will be free to attach to itself nucleotides or their precursors from the environment within the cell, to replace each complementary base that was separated from it in the unwinding and bond breaking" (*9*, p. 376).

"Cells of the archesporial tissue (the endothecium) divide and redivide at various angles to form a massive sporogenous tissue" (*10*).

"Each of these [rotating rings of gas] would condense to form a planet" (*1*, p. 74).

Use of the infinitive in the manner of the last two examples is so very prevalent that we must assume that authors, editors, and readers (and lecturers?) consider it unobjectionable and will defend it. Of those who insist the matter is one of far-fetched interpretation ("you're quibbling") we may ask at what point in the graded series they can confidently plan to change a speech habit. And even if they do stop short of undeniable teleology, are they confident that students will do so—that students will not slip into uncritical acceptance of overt as well as subtle teleology? Others may feel that the infinitive in these cases is the most direct and simple mode of expression, and that its avoidance would require "awkward circumlocution." There is a simple remedy, however; substitution of *and* for *to* is quite sufficient in the majority of instances that are not complicated by other infections of animism or anthropomorphism.

Teleological Thinking

And it is this very point, that generally a mere substitution of *and* for *to* will eliminate the most common examples of teleological phrases, which discloses the real danger behind the use of these phrases in our teaching. The danger is not that we teach "unscientific" terminology but that we are actually thinking teleologically and communicating these modes of thought to students. How else can we interpret the circumstance that, when two sentences differing in but a word can be formulated (compare "hydrogen and oxygen combine *to* form water" with "hydrogen and oxygen combine *and* form water"), we apparently find it easier to formulate the one with teleological overtones? If the alternative formulation appears awkward, it would seem that the awkwardness is not due to circumlocution but to interference with our predilection for certain modes of thought.

To return to the evidences of objectionable expressions in books, let us note another too frequently employed word, *for*. This time the series is arranged to show the more subtle usage first and the overt examples at the end:

"They [insects] have solved the problem of flight, which gives them immense advantages for dispersal, for seeking out appropriate growing places for their young" (*11*).

"Resting spores of the akinete type, which are structures for tiding the alga over unfavorable periods, usually germinate into a vegetative filament as soon as favorable conditions return" (*3*, p. 285).

"In the insectivorous or carnivorous plants, e.g., Venus flytrap, bladderwort, and pitcher-plant, leaves are modified for the capture of insects and other animals" (*7*, p. 531).

"There has to be some sort of mechanism for raising sap [in trees], and energy is lavishly expended in the process" (*2*, p. 139).

"Because of the unique ability of leguminous crops to convert nitrogen—from the soil nitrate or ammonia, or from the air—into bulk protein for feeding animals and other purposes aboveground, and for addition to the stock of organic matter and of plant-available nitrogen in the soil, the crux of food-supply on the modern scale is to render enough of the earthy nutrients, and of lime, phosphate, and potassium especially, available to the legumes" (*12*).

"In order for growth to occur, materials must be taken from the environment and incorporated into the developing body" (*9*, p. 17).

Sometimes a word with obvious teleological connotation becomes so familiar in limited context that it becomes a conventional term, a quasi-technical word, no longer subject to criticism. One which is almost at that status in biology is *store* and its derivatives. *Store* connotes provision for the future—purposeful accumulation. A better choice is *accumulate* (or its derivatives), since it is noncommital concerning purpose or intent. Although it may be claimed that *store* in the biological sense has a special and irreproachable meaning, it is to be doubted whether students change their understanding of the word when they enter and leave the classroom. Of the next four examples, those combining *store* with *reserve* or *function* are especially likely to lead students astray, but none of the examples would suffer if *accumulate* were substituted:

[In a description of food chains], "Others, the consumers, will be present because, directly or indirectly, they can utilize the food and its energy which is provided by the producers, whether it is an excess they have stored or the producer itself, usually after death" (*13*).

"Starch is stored by plants in tubers, seeds, and fruits, and a similar substance called *glycogen* is stored by animals in the liver" (*4*, p. 424).

"In some plants, e.g., *Portulaca* and century plants, the thick leaves function as water storage organs" (*7*, p. 531).

"Cells of Dinophyceae store their photosynthetic reserves as starch or as oil" (*3*, p. 151).

Somewhat akin to the question of *accumulate* versus *store* is the substitution by many biologists of *interphase* for *resting phase*. Curiously, the objection to *resting phase* as applied to a nucleus has generally been that the nucleus is quite

active metabolically during this phase. But, irrespective of whether or not the nucleus is active, the very notion of a nucleus *resting* between divisions should have been considered to be far too anthropomorphic. Yet despite the twofold argument against *resting phase,* this phrase retains some degree of currency, presumably because it is considered a technical expression.

Even if careful biologists are willing to substitute *interphase* for *resting phase,* they have no similarly easy choice for various other words which impart more or less technical meanings—for example, *dominance, competition, selection,* and *function.* If not carefully used, such words lose the respectability granted to technical terms and communicate their intrinsic connotations of anthropomorphism, animism, or teleology. This is, I think, apparent in connection with *function* in some of the previous quotations. *Selection,* for which some biologists expect absolution because its unfortunate implications are freely admitted, is hardly innocuous when it is described as entailing a choice by the environment, as in the following:

"*Artificial selection* is a process similar to natural selection, except that the variants that leave the greater progeny are chosen by man rather than by the general environment" [italics in the original] (*9*, p. 247).

Perhaps these examples from biology textbooks represent merely unfortunate choices of words for concepts which are not in themselves unsound. We can hope so, and leave analysis of the concepts to the philosophers of science, since our present concern is with the words per se and their effect on students' thought. But in physics there is used a familiar word which surely must disturb some thoughtful students, and as for the idea it represents, see what Erwin Schrödinger (*14*) has to say: ". . . the notion of force, the most dangerous relic of animism in this science." "Force," a cornerstone of Newtonian physics, a word and a concept that pervade our language and our thinking—if this is suspect, then what of the vocabulary of the less exact sciences?

Hints at the Supernatural

Not the least of the nonrigorous language habits in science teaching is that of implying the activity of a supernatural being. To the beginner, the idea of natural law presupposes a lawgiver, and this extrapolation is confirmed when we state that phenomena occur in obedience to natural laws, or when we imply such obedience by the words *must* or *has to.* For example, in one lecture I declared that an excited electron has to give up the absorbed energy when it returns to a lower energy level. A bright student should have pointed out that the electron doesn't *have to* give up the energy, it just *does.* In like manner, the idea of a planner may be conjured up by the idea of order or plan in the universe, particularly if other words support the inference. Note the mutual reinforcement of *plan* and *constructed*:

"It was he [Copernicus] who revealed to us, in its broad outlines, the plan upon which the Universe is constructed, or at least that part of the Universe which is of most immediate interest to us" (*15*).

Or, isn't it a sublimation of tendencies toward supernaturalism when nature is personified (deified?):

"For we know, from ordinary observation, how exceedingly wasteful and haphazard are nature's means of securing her ends" (*1*, p. 23).

These hints at the supernatural call to mind the "why" questions, which, admittedly, are often thought-provokers. Not uncommonly these questions do not provoke beginners into causal thinking, and insofar as they tempt students into seeking reasons other than causes, questions such as the following would be more appropriately put to a class in metaphysics than to one in science:

"Why, for example, should the proton have eighteen hundred times the mass of the electron?" (*1*, p. 188).

"It [Bohr's theory] left unexplained such questions as why an electron preferred a small orbit to a large one, why in its jumps it chose one small orbit in preference to another, why it could not move in other orbits than the discrete ones required by the hypothesis" (*4*, p. 321).

It is very easy to explain to the student that "why" in science requires a mechanistic rather than a teleological answer. It is not so easy to get him to adhere to this requirement, especially in biology. Rare indeed is the student who will explain "why a salmon swims upstream" in mechanistic terms. Incidentally, I have found considerable shock value in confronting classes with two questions in succession: (i) Why does a potted plant bend toward a window? (ii) Why does a moth fly into a candle flame? At least temporarily the class realizes the advantage of rephrasing with "what causes . . . ," but more than a single device is needed to overcome the continuous beguilement into teleology, animism, and anthropomorphism to which our students are subjected.

I will not attempt to classify the remaining few quoted pasasges. In addition to the specific words which are objectionable (italics mine), the general tenor of these passages seems unnecessarily nonrigorous:

"In Infusoria, where the macro-nucleus normally divides in this *artless* way [amitotically], the micro-nucleus divides mitotically. The whole process of mitosis is an elaborate way of *ensuring* that the genes which are localized in the chromosomes shall be exactly distributed among the daughter nuclei (*16,* p. 69).

"Obviously blood *must not* clot inside the blood vessels, *as it would block the circulation . . .*" (*16,* p. 145).

"As the temperature increases the molecules become more and more agitated; each one bounds back and forth more and more vigorously in the little space left *for it* by its neighbors, and each one strikes its neighbors more and more strongly as it rebounds from them" (*8*, p. 44).

"So *eager* are sodium atoms *to lose* electrons, *so anxious* are Cl atoms *to receive* them, that the combination is extremely violent, accompanied by the evolution of much heat and light" (*4,* p. 335).

But why worry about it? Few of us would offer a brief in support of teleological language, but can't we be tolerant of occasional contaminations? Must our language be made aseptic? I maintain that we should try, and this means giving more than lip service to the attempt. Lip service is not merely insincerity; it may lead to unjustified feelings of security. In one of his expositions of operationalism Bridgman makes a point that applies here. He says (*17*), "The true meaning of a term is to be found by observing what a man does with it, not what he says about it." So also, though we *say* we are against teleology and all the rest, we *use* these ideas in our language and thereby display the extent to which they affect our thinking.

Suggested Remedies

What can we do about it?—other than be more careful, that is. Carefulness is a rather passive approach; it may protect students from being led astray, but it is hardly likely to teach them to avoid the pitfalls consciously. If a little class time can be devoted to the problem, it can be a rewarding topic, not only for its

own sake but for its reinforcement of other topics. The following active approaches have been used in a large class (400 students) to sufficient advantage to encourage further attempts. First, we presented justification for our avoidance of the teleological, animistic, and anthropomorphic viewpoints, as follows.

1) When mechanistic explanations are available, teleology and its allies violate the principle of parsimony. (Pointing this out is one of the easiest means of elucidating the application of Occam's razor.)

2) Teleological and similar elements of explanations are probably never heuristic in the natural sciences. (We used this point to reinforce discussion of the criteria of a good theory).

3) Questions formulated in teleological and similar styles are "meaningless" in the sense that they are not susceptible of scientific investigation, whereas restatement in rigorously mechanistic or operational terms will often indicate the means of attacking the problem. (Substitute *what causes* in questions that begin with *why*).

To pursue this active approach, we attacked textbook statements, some of which are quoted in this article. Sometimes passages were dissected in class; others appeared in examination questions. This was disconcerting to some students, who found it unorthodox to challenge the printed word. Since rejection of the method of authority is often taught as a feature of the scientific attitude, we feel that the technique was valuable.

It is realized that some will consider such techniques to be distractions from what the author or lecturer is trying to teach. Indeed, the whole matter may be dismissed as a disproportionate concern with words at the expense of course content. But what is the lecturer trying to teach? What should be the content of science courses which, usually, purport to satisfy the objectives of a liberal-arts curriculum? In view of the differences between the traditional content of physics and chemistry and biology, it seems unreasonable to claim that these different contents are equivalent for satisfying liberal-arts requirements. Rather, we should reexamine one of the platitudes—"teach them how to think." If this is what the lecturer hopes to teach, then an occasional distraction from the factual material is not only justified, it is essential.

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AAAS Washington Meeting

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The preliminary announcement of the Seventh Washington Meeting [*Science* **127**, 1246 (23 May 1958)], which will be held from 26–31 December, inclusive, has indicated the scope of the programs of the AAAS as a whole, the 18 sections, and of the nearly 100 participating organizations.

The synopses of the programs, which began to appear in *Science* with the 7 November issue and are concluded on page 1438, have provided additional information—but only the General Program-Directory, which will reach advance registrants by first-class mail in the next day or so, can furnish a full appreciation of the number and quality of the more than 300 sessions. The editorial on page 1391 points out a few of the highlights. It is manifest that this year's 125th annual meeting of the Association will be particularly interesting and significant.

The Annual Exposition of Science and Industry, the largest and most varied in recent years; the unusual number of carefully selected, prize-winning foreign scientific films; the first demonstration of a new, much improved, closed-circuit, color television system; the special events for women—any one of these might make a visit to Washington worthwhile—merit special consideration. There are, however, programs of interest to specialists in all the principal disciplines, strong interdisciplinary symposia, and a number of programs of concern to all scientists. A conspectus of these events follows.

AAAS Special Sessions

One of the characteristic and most important features of the annual meetings of the Association is the series of outstanding general addresses by distinguished authorities, sponsored by organizations that meet regularly with the AAAS. These special events are joint sessions with the Association and are open to the general public of the city in which the meeting is held.

AAAS Presidential Address; 28 Dec., evening; Wallace R. Brode, science adviser, Department of State, and president of the AAAS, presiding. "Fifty years of medical genetics," by Laurence H. Snyder, president, University of Hawaii, and retiring president of the AAAS. Preceding the address, Leonard Carmichael, secretary of the Smithsonian Institution and general chairman of the Washington meeting, will speak briefly. Following the address there will be an informal AAAS presidential reception in the ballroom and adjacent rooms of the Sheraton-Park Hotel. All registrants and members of the local committees are cordially invited to attend.

Joint Annual Address of the Society of the Sigma Xi and the United Chapters of Phi Beta Kappa; 29 Dec., evening. "Science and public policy," James R. Killian, Jr., special assistant to the Presi-