Knowledge: a Growth Process

Knowledge grows like organisms, with data serving as food to be assimilated, rather than merely stored.

Paul Weiss

It seems appropriate for a member of the American Philosophical Society for Promoting Useful Knowledge to review for himself on occasion the philosophy by which useful knowledge is promoted. I have indulged in such a private exercise, not as a philosopher, which I am not, but as a practitioner of science. In our day, promotion of knowledge has become a public trust. Its managers and practitioners must see and keep the object—knowledge—in sharpest focus, lest it get blurred in the excitement of a mass-production boom, or get disjointed by progressive parceling among producers, sponsors, distributors, interpreters, administrators, and consumers.

Promoting knowledge can only mean fostering its intrinsic growth. To do this rationally requires insight into the nature of the growth process. I wish to show that, fundamentally, our knowledge grows the way a living body does. The kind of knowledge I shall deal with is scientific knowledge, implying no inference to other forms. And even this limited perspective is slanted from the angle of my specialty, the life sciences. Yet, it takes the vantage point of a biologist to recognize the growth of knowledge as truly a mirror image of the growth of organisms. Not long ago, I summed it up as follows: "Scientific knowledge grows like an organic tree, not as a compilation of collector's items. Facts, observations, discoveries, as items, are but the nutrients on which the tree of knowledge feeds, and not until they have been thoroughly absorbed and assimilated, have they truly enlarged the body of knowledge" (*1*). This thesis I shall now try to expound.

The author is member and professor at the Rockefeller Institute, New York. This article is based on a paper read at the meeting of the American Philosophical Society, Philadelphia, 13 November 1959, and is being printed simultaneously in the *Proceedings of the American Philosophical Society* **104**, No. 2 (1960).

My model is a higher animal. The main steps of its growth process are diagrammed in the upper half of Fig. 1, with boxes indicating material entities, and arrows, the flow of processes connecting them. Growth converts food from the environment into body substance in a sequence of four major steps: intake, digestion, assimilation, and final utilization. The raw materials are gathered from the environment and either stored or passed on directly for alimentary processing. Digestible items are broken down chemically to more manageable compounds, which are then screened and sorted into useful and useless varieties. The wastes, together with undigestible residues, are eliminated, sharing the fate of spoilage from protracted storage. The useful items, the true nutrients, are circulated to the tissues, whose cells pick what they need, then recombine and modify it to form intermediary products, already bearing specific earmarks of that organism, some to be recirculated for use by other cells, some still to be discharged as waste; and finally, culminating the synthesis, each cell constructs from this supply pool selectively the substances and structures uniquely characteristic of its own kind. In this last step, cells branch in two directions: They either reproduce, that is, add more cells to the body; or they turn to the manufacture of special products, like fibers, hair, secretions, bone, and such.

This model is abridged and oversimplified. However, it illustrates the essence of the growth process, which is that in its growth an organism never adopts foreign matter outright, but reorganizes and assimilates it to fit its own peculiar pattern. Even a leech must first dissolve the hemoglobin of its meal of blood and then compose its own brand from the fragments. Organic growth is by assimilation, not accretion. Food items are not simply stuck on to the body, but, on the contrary, lose their identity and become anonymous and indistinguishably blended into the body's very own type of constituents by the processing chain of extraction, screening, sorting, fitting, and recasting.

How closely this course is mirrored in the growth of knowledge is symbolized in the lower half of Fig. 1, beginning from its source—experience, still unprocessed. Probing of the environment furnishes the raw data of information, which are either stored as records for future use or analyzed forthwith. The products of analysis are then screened and sorted according to relevance. Irrelevant ones go into discard, sharing the fate of records become obsolete. And from this sorting, the pile of data emerges as an ordered system, catalogued and classified, yet each item still revealing its erstwhile identity. The grandest examples of such ordered sets of data are perhaps the Linnean system of species prior to the theory of evolution, or the Mendelyeev Atomic tables prior to modern physics. In various stages of evaluation, such packaged information is then widely circulated, leading to confluence and critical correlation with countless contributions from other sources. From this synthetic process, hypotheses emerge, which, upon further verification, turn into integral parts of the body of knowledge—theorems, principles, rules, and laws—general formulas which not only supersede the itemized accounts of the very data from which they were derived, but can dispense with the further search for items of information, which they predictively subsume.

At this stage, data have become assimilated, have lost their individual identities in merging with that higher entity—the body of organized knowledge. Sheer listing has given way to understanding. A patchwork of unrelated facts has been transformed into a rationally connected thought structure of inner consistency, viable and durable, subject to the tests of survival and the adaptive improvements of evolution—a veritable model of an organism. As in the organism, the culminating phase is branched: as basic knowledge grows, part of the increment accrues to its own body, yielding more basic knowledge, while another part is converted into differentiated products—all that is commonly lumped under the attribute "applied."

Note that no separate express tracks connect either foodstuffs directly with functional products in the organism, or informational data with practical results in human affairs, but that both must be routed through the common machinery for growth. In knowledge, as in nature, fruit grows on trees and cannot be raised directly on the soil by short cuts bypassing the tree.

Our growth analogy could be expanded—tradition standing for heredity; novel ideas, for mutations; the "team" approach, for symbiosis—but the general parallelism will have become clear enough for us now to examine its implications.

In the first place, it shows that information is not tantamount to knowledge. Information is but the raw material, the precursor, of knowledge. To hoard a store of unrelated items of information in a mental gullet by rote memory and without sense of relevance —including the ability to regurgitate the data on a quiz master's prompting—should pass for knowledge no more than the stuffing of a hamster's pouch can be regarded as growth. Knowledge emerges from the distilling, shaping, and integrating of the raw material into concepts and rules; and in this process of condensation and generalization, the number of bits of detailed information dwindles, rather than mounts: a piling up of raw data signals glut rather than growth.

Accordingly, if knowledge grows like organisms, we ought to observe sound dietetics and avoid unhealthy overstuffing; the symptoms of glut—redundancy, superdetermination, oversophistication, and just plain bulk—are already noticeable in current research practices. Part of the syndrome carries rather undignified names, such as "soft money" or "projectitis." But the crucial ailment is myopic vision, which fails to recognize the true character of knowledge. Once out of sight, the body of concepts to which data collection should be related no longer guides the search for data. The sense of relevance and selectivity becomes atrophic, composing stops at sheer compiling, search becomes pointless, and freedom of investigation degenerates into license for random movements.

The diagnosis calls for preventive therapy. One nostrum proposes that research be governed, with social utility as the beacon. Unfortunately, the diet this prescribes for knowledge is of the sort that social insects feed to their larvae to mold them to preordained stations in life, mostly soldiers and sterile workers, instead of nurturing versatile and reproductive specimens. By contrast, I submit that knowledge grows best on a liberal balanced diet based on variety and wide freedom of choice, free of excessive roughage.

Now, who is there to write the formula? We all abhor the notion of an all-wise potentate of knowledge, whether person, institution, or society, to rule on what will, and what will not, promote the growth of knowledge. But there is one wizard, who has the formula and gladly hands it over for the

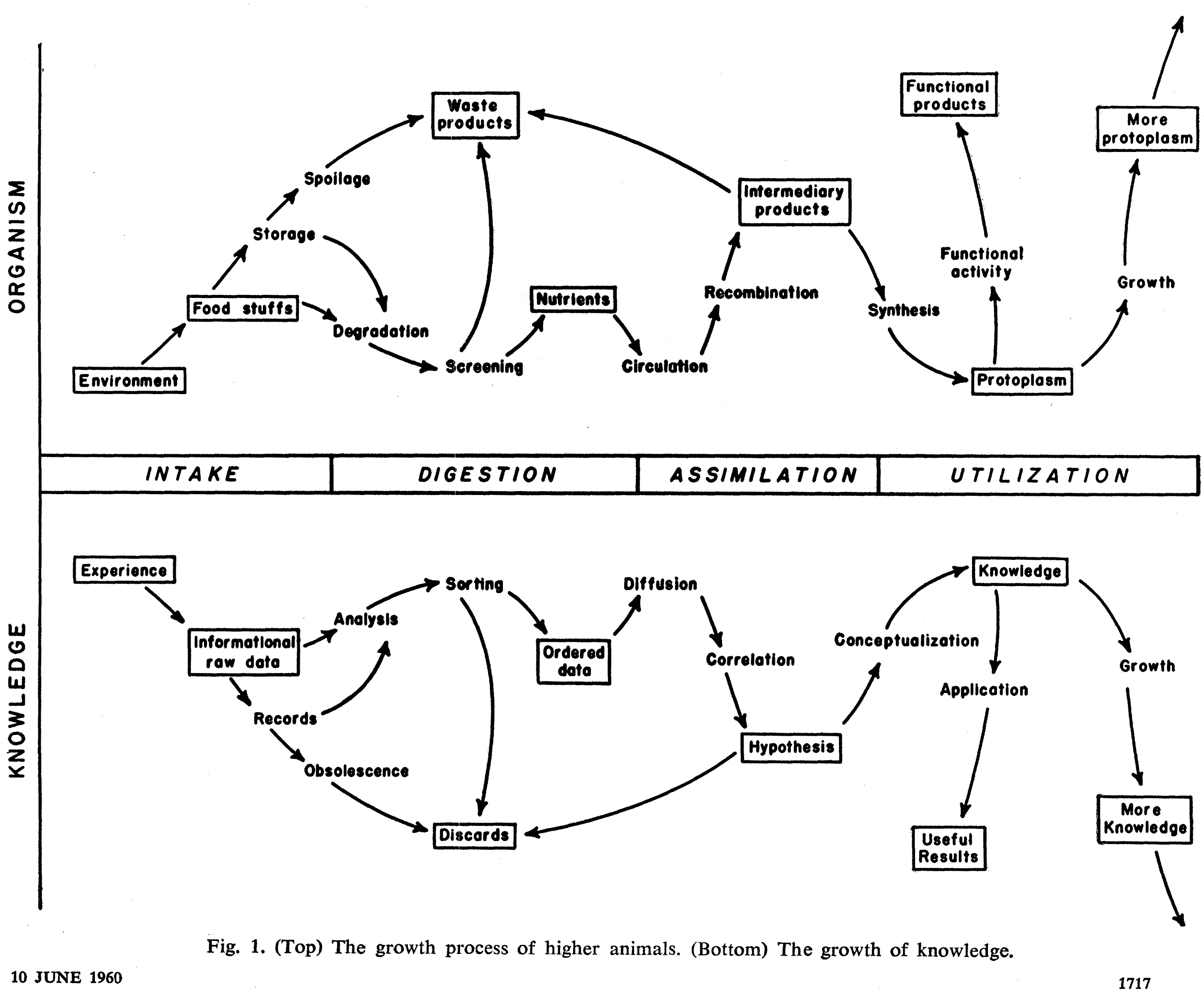

Fig. 1. (Top) The growth process of higher animals. (Bottom) The growth of knowledge.

asking—history, which has watched knowledge grow from infancy. It tells us that the key agent in the growth of knowledge has always been the human mind, imaginative, critical, and integrative; devising robots, tools, and techniques merely as aids to extend the limited reach of man's perception and control, but never abdicating the functions of evaluation and invention. Promoting knowledge, therefore, implies giving full scope to the exercise of the faculty for assimilation and synthesis by which the mind converts facts to knowledge. The history of knowledge contains the rules to give those bent on promoting knowledge by either doing or supporting research the necessary cues for intelligent and responsible self-direction. The stress here lies on "self"; there is no need for forcible external steering: bearings for self-steering are needed. But how could the uninitiated self orient itself purposefully if we hide or blur the goal? Or do we expect each self to rediscover the goal for himself by trial-and-error, fumbling and floundering in semidarkness, when we could readily draw on the lessons of the past to illuminate both goal and path?

You realize what I am driving at. As educators we mold tomorrow's promoters of knowledge. We must be far more explicit than we have been lately in teaching them not just the present state of knowledge, but the way in which it has grown up to here, which is the only way in which it can grow further. Inspired teachers teach and practice it, but they are too few. Some students find it by themselves, but not enough of them. So, let us restore to education some fundamentalism—making explicit to the student the fundamental bearings needed for him to chart his own course in clear view of what furthers knowledge and what does not, instead of letting him drift in the cross currents of traditional momenta and alluring fashions. Ideas—yes, even well-founded speculation—should find a respectful place again among the shining gadgets. And his critical mind, rather than the board room of a fellowship or grants committee, should become again the primary testing and screening ground for relevance. If he finds data, let him explain their meaning. And if he can't he should have a sense of incompleteness, and not of glee over having prevented mental contamination of nature. Let editors encourage, rather than blue pencil, an author's interpretive excursions. And let the whole process of fostering knowledge become refocussed on penetration and concentration, instead of sheer expansion and bulk. Or else, knowledge—an organism—might come to share the fate of the dinosaurs.

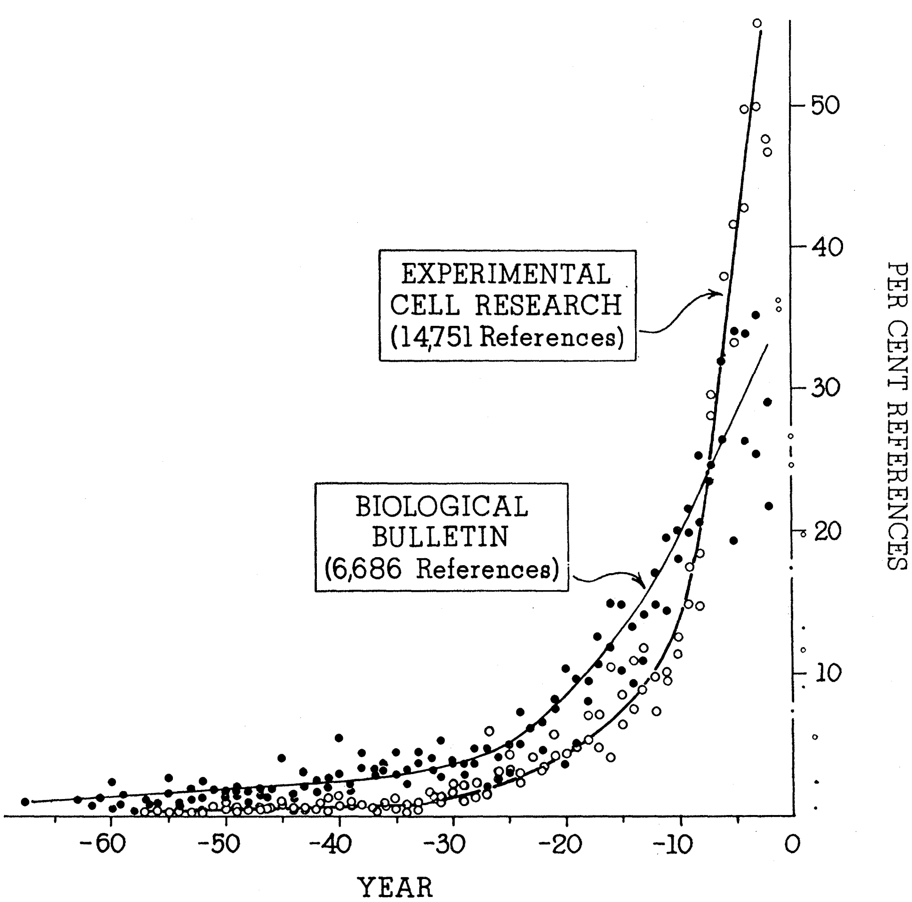

Fig. 2. Annual percentages of references to works published a given number of years previously.

Yet, notwithstanding this plea for more thorough digestion and mental processing of data, there is another side of nature which is refractory to this treatment and does not fit our analog at all. I am referring to those phenomena whose constellation in space or seriation in time is so unique that generalization would obliterate their most relevant features. We can establish general principles of parasitism, but each species of parasite has its own peculiar life history, which must be known as such. Chemical chain reactions must conform to thermodynamic law. But just what sequence of steps constitutes a given metabolic cycle must still be determined separately in each instance. Despite their common name, each hormone has its own special way of operating, and each disease has its specific course. In other words, the information which in the search for basic knowledge would merely be a way station, becomes a terminal; to remain useful, its itemized character must be preserved.

This seems the proper province of automation, relegating increasingly to technological devices the jobs of recording, scanning, sorting, reducing, storing, and retrieving data. But even here human intelligence will have to judge what to explore and to record. As every single walnut is unique, can we afford to go on indefinitely shelling walnuts and loading down our libraries with records of their physiognomies? Certainly not, unless there is a point to it. To make the point is up to the investigator. But it is up to educators to imbue investigators with a sufficient sense of relevance and responsibility as to abstain from pointless tasks. Self-direction must not be let lapse into self-indulgence. But how draw the line? Whether to stop at pragmatism or to go on to generalize varies, of course, with subject matter, need, and interest but, above all, perspective.

To gain perspective, let us again turn to history. What is—so we may ask—the real fate of plain recorded data? What is their life expectancy, and does it differ substantially for data that can be generalized and those that cannot? Since mere occupancy of library space is no criterion of life, as against mummification, I made a little actuarial study, using as a gauge of relative vitality of data the frequency with which they are referred to in the literature.

For comparison, I chose two biological journals: *Experimental Cell Research*, with a strongly analytical emphasis, and the *Biological Bulletin*, with a larger descriptive bias. I tallied all references, except self-citations, by all authors year by year over a 10-year period and plotted the percentage frequency with which publications were cited lying back 5, 10, 15, 20, and so forth, years. Figure 2 shows the results, which are quite striking (*2*).

For each of the two journals, the annual percentage frequencies define with remarkable consistency a single curve, whose course expresses the rate of obsolescence of publications. The steepness of its slope should give us pause. No more than 50 per cent of the annual references in *Experimental Cell Research* date further back than five years, and still older literature is rapidly lost sight of. By contrast, the flatter curve for *Biological Bulletin* reveals a much greater dependence on older records. The difference is highly significant. To validate it further, I plotted the chronological frequencies of back citations during 1952–1954 in the major journals in physiology and in zoology and entomology (Fig. 3) from a report on "Scientific Serials" (*3*), and obtained an essentially similar pair of curves, both dropping off sharply, but the drop being much steeper in analytical physiology than in its more descriptive biological sister sciences.

The lessons of this actuarial census of literature thus are twofold: In the first place, the active life span of pure data is at any rate amazingly short: they die of either assimilation or oblivion. And second, the less they lend themselves to assimilation, the longer they remain useful individually.

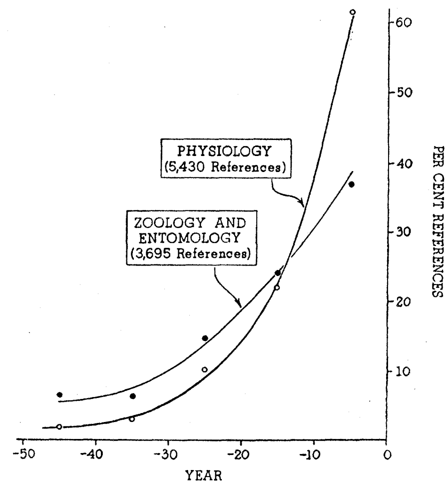

Fig. 3. Percentages of references, in the major journals in physiology and in zoology and entomology, referring to work published a given number of years previously.

This leads me to conclude as follows: Each field of knowledge must be accorded its own merit ratio between generalization and particularization, it being taken for granted that assimilation will be driven to the utmost limits compatible with the nature of the field. Yet, in view of the rapid attrition of *all* unassimilated information, a radical reorientation of our publication policies would seem warranted, based on introducing the principle of actuarial tables, about as follows:

In each discipline separate media of publication would be established for classes of communications of different life expectancies. Each author of a manuscript would assess its prospective useful life span—presumably with the benevolent advice of editors—on a rating scale extending from the ephemeral technical note at the low end to the great synthetic opus at the other; the paper would then be allocated to the corresponding fast-aging or slow-aging class of serial. Each serial volume would be kept on library shelves only for the time span allotted to its class, and then discarded, except in a few libraries specifically designated as permanent historical repositories. Some such deliberate scheme would go far in restoring and preserving a reasonable ratio of payload to ballast in our records of knowledge.

Graded in terms of relevance, not every observation is worth reporting; not every report is worth recording; not every record is worth publishing; and not every publication is worth preserving for eternity, except in sample specimens as in Noah's Ark. I submit that this grading can still be left to the investigators and their peers, as long as they are cognizant of the true nature of knowledge as a growth process, of which assembling facts—of food for thought—is but the first preliminary step; a growth process, moreover, which often thrives better on a spare than on an overly rich diet, and in which self-restraint can readily ward off obesity.

So in conclusion, and dropping parabolic language, the effective pursuit of knowledge is intimately linked to the old virtue of disciplined research morale which will not countenance the substitution of bigness for greatness, gadgets for intellect, projects for ideas, and man-hours for thought; although it must rely to the fullest on technical relief by gadgets and man-hours in those auxiliary services which do not require the intervention of a constructive mind.

As I said at the outset, my comments are confined to *scientific* knowledge. Its steady long-range growth has still immense potential scope. We should not let it get diverted, inflated, and unbalanced by pressures for short-range crash spectaculars. More than ever, our key words should be *balance* and *perspective*.

References

1. P. Weiss, "The Message of Science," *Occasional Papers from the Rockefeller Institute No. 1* (1959).
2. The assistance of Mrs. Sybil Bush in compiling the data is gratefully acknowledged.
3. C. H. Brown, "Scientific Serials," *Association of College and Reference Libraries Monograph No. 16* (1956).