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BIOLOGY IN THE NEXT TWO DECADES: CONTINUED

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The discussion on "Biology in the Next Two Decades" by the commissioners, as reported in the October, 1969 issue of CUEBS NEWS has led me, as a member absent from that discussion, to respond to some of the comments there, in the spirit of the newer thinking called for by Dr. Henry Koffler.

Contributions of Biology to Science in General

The outstanding contribution of biology to science in general seems to be the initiation of a general theory of evolution. The theory of the origin of species, as supported by Darwin's extensive evidence, has influenced our thinking for more than a century. After almost a quarter of the 20th century had elapsed, serious attention consistent with disciplined knowledge was devoted to the origins of life (Oparin, Haldane, Groth, Herrera, etc.). Even earlier, astrophysicists (Edington, Chamberlain) began to think and write in terms of cosmic evolution. Today, such phrases as "stellar evolution" are commonplace in the scientific literature.

By including Darwin's published concepts of the evolution of *moral sense, mental powers,* and *social faculties,* we are able to construct a continuum of general evolution. In simplified form, the flowsheet of the general theory of evolution has the appearance: Cosmic origins Galaxies stars stellar systems (Solar System) inanimate Earth biotic Earth (first organism) evolved species (man) abstract qualities (mental, moral, and social attributes). One can spell out in detail how advantage-conferring abstract functions would be subject to the selection process. This general picture of a comprehensive evolution is, I believe, gaining ground and is of much subtle value to students whose scientific education has come to them mostly in discrete parcels.

The basic idea of a cosmically total evolutionary sequence began its life within the science of biology. Inasmuch as the concept was in essence valid and inseparable from other natural phenomena, this outlook represents a fundamental contribution of biology to all science.

That a comprehensive theory of evolution should have its beginnings in biology seems most fitting since the observer and interpreter is man, himself a product of biological evolution. As stated, one potential educational benefit of the evolutionary concept, applied throughout a comprehensive continuum, is that it may knit together the swatches of the overfragmented sciences, with the strong thread of the evolutionary sequence.

Dr. Koffler also spoke of the need for generalizations in biology and asked if the biologist can ever generate broad generalizations. I believe that we can do so at the level of discerning applications of physical concepts to the questions of the origins of living systems, and from there to their further evolution. I would attempt to do so, as follows.

New Generalizations Concerning Life and Its Origins

Some of the inferences related here are not entirely new, but are rather new emphases of generalizations already partly expressed in the literature of biology. Whether new in entirety or in emphasis, the principles which are viewed as geologically relevant emerge from experimental studies.

Perhaps the reason that some interpretations can now be generalized is that rigor has been introduced into biology in two ways. One is through the superposed perspectives of biology, chemistry, geology, astronomy, and physics. Another kind of rigor results from the fact that biological phenomena can increasingly be viewed from two temporal outlooks, the contemporary and the primitive.

A number of the meaningful experiments have been constructed by extrapolation of biological facts to inferred prebiological conditions, and many of the conditions have been found to be geophysically relevant even contemporaneously.

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Historical

The doctrine of spontaneous generation has recovered from the "mortal blow" of Pasteur's simple experiment, despite his prediction of 1864 that it would not do so.[a]

The concept of spontaneous generation in the broad sense is more properly referred to in the 20th century as self-assembly.[b]

A necessary precursor material[c] for such self-assembly and processes leading to production of such material and to organization thereof have been identified.

Modern Broad Outlook

Life is an organized manifestation of matter at a particular stage in the evolution of matter.[d]

Complex Nature of Life

Life is composed of microsystems,[e] each of which is an association of simply derived materials and a number of simple processes. The complexity is the result of interactions during constructionistic evolutionary processes. The contemporary complexity includes a composition of nucleic acids, proteins, lipids, and small molecules and the functions of enzymes, membranes, and replication.

Nature of the Origin of Life

The inference from experiments is that life arose essentially as microsystems[f] which assembled themselves from self-ordered polyamino acids. The self-ordering[f] had its roots in the varied amino acids which polymerized.

Conditions Necessary for the Origin of Life

In order for life to originate from amino acids (1) anhydrizing conditions such as temperatures above the boiling point of water (or a phosphoric medium), and (2) water in a second step were or are needed.[g] The requirement was for those conditions in that sequence.[g]

Ease of Origin of Primitive Life

According to the experiments and the geological relevance[h] of the conditions, primitive cells arose easily, quickly, and innumerably on the planet Earth. Primitive cells (e.g., *sans* nucleic acids) could have arisen from reactive gases in less than 12 hours.[i] The inferred prolific nature of primordial life is consistent with the prolific nature of contemporary cellular life.

Nature of the Evolution of Primitive Life

The evolution from primitive life has proceeded under the selected influences of the component material (and systems) in extrapolation of the selected prebiological processes. A consequence of the "self-limiting"[j] evolution is the "unity of biochemistry."

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[a] The exact quotation of L. Pasteur is, "Jamais la doctrine de la génération spontanée ne se relèvera du coup mortel que cette simple expérience lui porte" (Never will the doctrine of spontaneous generation recover from the mortal blow struck by this simple experiment.)

[b] Fox, S. W. 1968. Spontaneous generation, the origin of life, and self-assembly. *Currents in Modern Biology,* **2:** 235-240.

The essential idea that the appearance of cells could be attributed to an act of self-assembly has been expressed by Wald (*Scientific American,* August, 1954) and in the context of a negative answer by L. Pasteur ("Can Matter organize itself? In other words, are there beings which can come into the world without parents, without ancestors? That is the question to be resolved").

[c] A necessary precursor material is a heteropolyamino acid, which could be produced by the simple heating of amino acid mixtures containing any proportion of aspartic acid or glutamic acid. By simple heating or other anhydrization, such mixtures can yield proteinoids, polymers of high molecular weight with a simultaneous content of each of the amino acids common to protein. The first proteinoids on Earth did not necessarily contain all of the amino acids found in contemporary protein; they likely contained most or all of them, inasmuch as many types are simultaneously produced in many of the experiments simulating the prebiological synthesis of amino acids. (Families of amino acids are also found in lunar dust and in meteorites.)

[d] The evolution of matter has been traced by interdigitating studies from cosmic origins through the first life to the abstract functions of man, as stated earlier.

[e] This is in part a restatement of the Cell Theory (Schwann, 1838).

[f] The published evidence for such self-ordering is of many kinds. Viewed within the theory of general evolution,[d] the self-ordered polymer and the self-assembled microsystem are consecutive stages in an evolution of matter. The order inherent at any one stage of the total interdigitated sequence was transduced to another kind of order at the next stage. With the trapping of energy from the Sun, further ordering within the microsystems became possible.

[g] The anhydrization was necessary to overcome the energetic barrier in formation of the peptide bonds. The water in the second step would have been necessary to trigger the self assembly. The two steps simultaneously, or in reverse order, would fail. Some writers have noted that the surface of the Earth was largely aqueous. Even if true, this does not signify that the surface was entirely aqueous. The contemporary terrestrial surface is a mosaic on which steps (1) and (2) are likely occurrences. Evaporation of aqueous solutions of proteinoid to yield microspheres was also a likely frequent occurrence. Many possibilities for geophysical sequences of (1) and (2) have been described in publications.

[h] Those conditions exist somewhat widespread on the contemporary Earth. As suggested also by others (Keosian, Oparin), life may be arising now, especially if amino acids are forming now. Charles Darwin suggested that *de novo* life or its intermediates might be consumed by life already here. Another explanation for why we may fail to see *de novo* life is that it resembles descendants of other primitive life so closely that we fail to distinguish its *de novo* nature, in that each time it arises it is similar to products or descendants of other natural experiments.

[i] While the experiments indicate that primitive gases could have evolved to protocells quickly, observation tells us that the evolution of primitive life to human life required 2 billion to 3 billion years. Should a catastrophe obliterate life on the Earth, new primitive life would, with high probability, emerge again. Should primate life be obliterated in such a catastrophe, the odds are high that human life would never again emerge in the Solar System. On the premise that the Universe is time-dependent, we moreover cannot anticipate that the next 3 billion years will see an evolutionary history similar to that of the last 3 billion years.

[j] The swath of the evolutionary pathway may be considered as limited by "constraints." However, a "limitation" and "constraints" often connote nonfunctional interactions. Perhaps a more likely explanation is that some molecular transformations proceeded further and faster than others, thus outrunning them in a positive, competitive sense. This explanation is also consistent with the concept that new species emerged as the result of greater trial-and-success. The selection appears to have had narrow borders of molecular variety. Thus we can understand the origin and maintenance of the "unity of biochemistry."

This narrowness of molecular heterogeneity appears to be in contrast to morphological variety, although even here diversity may not be great, e.g., the many animal species which are quadrupeds. Perhaps we simply recognize morphological diversity much more easily than chemical diversity.

Some have inferred a common single evolutionary precursor of all life. A compelling alternative to that concept is that any *de novo* life resembles other *de novo* life.[f,h] This interpretation arises from the fact that the course of prebiological molecular evolution appears to have borders as narrowly close as the evolution of life.

Cosmic Evolution[d] and the Synthesis of Amino Acids

The formation of amino acids from interstellar formaldehyde, ammonia, and water or from other intermediates is highly selective. The same amino acids tend to dominate the composition in experiments employing varied energy sources on varied simulated primitive reactants, and thus indicate similar results irrespective of the mode of molecular evolution.[h]

The Origin and Evolution of Informational Macromolecules

Experiments have led to the inference that "information" (see **Glossary**) in the geological matrix evolved to information in the individual. The information was thus inherent in mixtures of diverse monomeric amino acids in the geological realm. Those amino acids expressed their informational content by combining to form polymers in self-ordered sequences.[k]

An essential consequence of this analysis is the conclusion that no discontinuity existed from pre-life in the geological realm to living microsystems separated from the environment by membranes.

Inheritance and Evolution

As processes of inheritance became more complex, the individual cell became increasingly independent of the environment. An outstanding advantage of the appearance of a genetic code was that the individual became more dependent upon his now more complex cellular constitution than directly upon the environment.

Evolution and Order

Life and its evolution do not violate the second law of thermodynamics. The second law is applicable to closed systems, whereas living systems are thermodynamically open.[l]

Component Questions of the Origin of Life on a Sterile Earth

Several major questions of the origin of life have been answered in principle. The various questions are treated in a footnote.[m]

[k]These polymers then express their informational content in specific interactions.

The individual microsystems then can express their informational content by compartmentalization, specific catalytic activities, accretive growth and unitary associations of assembled structures, support of bud-like appendages, microsphere-microsphere interactions, specific binding of polynucleotides and other molecules, etc. The experiments indicate that these functions could arise without nucleic acids.

[l]The Solar System as a whole may be a priori considered to be a closed system. The terrestrial biosphere is then an open system within that closed system. Energy may, for example, flow from one part of it, the Sun, to another, the biosphere or to individual subsystems in the latter. Ordered macromolecules and microsystems arise in that biosphere, much order being the consequence of energy input. The precursor systems were not, however, entirely disordered.

The evidence indicates rather that one kind of order arose partly from another kind of molecular order, for instance, arose from the order of shapes and forces of reactant monomers. One may trace the order of biological systems back to cosmic origins which yielded nonuniform matter, according to at least one analysis (Sakharov, A. D., 1965. The initial stage of an expanding universe and the appearance of a nonuniform distribution of matter. *Journal of Experimental and Theoretical Physics* (USSR) **49:** 345-358).

Geological Relevance

The degree to which one may develop a judgment of the probability that primitive life arose as indicated is a function of the extent to which the conditions identified in the laboratory existed in the geochemical realm. This assessment was found to have an unexpectedly high degree of rigor when the necessary conditions were recognized as widespread now. If one assumes the geological presence of amino acids containing any proportion of aspartic acid or glutamic acid (step a), what is necessary are temperatures above the boiling point of water (step b) followed by intrusion of water (step c) Such temperatures exist at or close to the terrestrial surface in literally thousands of areas of today's Earth. For intrusion of water (step c) only a phenomenon as common as rain is required. Numerous other geophysical situations are also germane, e.g., recessions of the seas (in which proteinoid was dissolved).

This set of occurrences required two steps. No real difficulty arises from the fact that conditions suitable for one step are unsuitable for the other, e.g., a planet such as Earth is a mosaic of lithosphere and hydrosphere. These experiments substantiate the theoretical thermodynamic reasoning employed at the outset. Numerous publications by others during 15 years have shown in dilute aqueous solution the formation of only small yields of small peptides, not substantially above the barrier erected by thermodynamic predictions for the reaction in dilute aqueous solution. Most organic chemists know, also, that water is an effective solvent for decomposition; even organisms carry out key reactions in relatively hydrophobic zones such as are found in ribosomes, small undissolved particles in the cell. On the primitive Earth, however, the formation of primitive cells triggered by water would have left these organic entities under layers of water which would have protected from further heat or destructive high energies.

The New Perspectives

The results of the experiments provide for the first time answers in principle to the following major questions of the origin of life:

1. *The origin of order in proteins when no large molecules and no code existed.*

[m]A Laboratory Explanation of the Spontaneous Origin of Primitive Life on Earth

The processes by which primitive cells could originate on Earth have been explained in principle by experiments in the laboratory.*

The essential steps are three:

a) Amino acids are produced by the heating, etc., of the components of organic matter known to exist in the Galaxy, ammonia and formaldehyde, or by the reaction of conversion products.

b) Amino acids are spontaneously heated in such a manner as to link together in (internally ordered) artificial proteins.

c) On contact with water, such proteins assemble themselves into microscopic systems having a number of properties of contemporary cells.

*While we may never know with certainty how life began, critical review of the evidence indicates that the area of speculation is being sharply reduced. In calling forth a judgment of the probability of its validity, the theory of the origin of life does not differ in principle from the atomic theory or the theory of the gene in their early stages in being significantly less than 100% certain. The atomic theory and the theory of the gene have had the opportunity to be challenged much more extensively; they continue, moreover, to undergo refinement.

The experiments have demonstrated that the information necessary for primitive biologically functional large molecules arose from the mixtures of diverse monomers from which they formed. This demonstration resolves a fundamental dilemma. No code, according to these experiments, was necessary at the first stage of life. The macromolecules formed and their internal selectivities constituted a simply derived precursor such as might have evolved to contemporary genetic systems.

These results, when combined with a recognition of other phenomena described below, explain that information latent in the pre-environment would be transferred by macromolecular synthesis and assembly to the first individual(s). The experimental findings also permit rejection of the hypothesis that any discontinuity existed between pre-life and life or between nonlife and life.

2. *The origin of enzymes when no enzymes to make them existed.*

Some authors have regarded this question as the most fundamental dilemma. The experiments show that appropriate geophysical conditions and mixtures of diverse amino acids yield molecules with weak enzyme-like activity. These molecules, proteinoids, have all or nearly all of the salient characteristics of some enzymes. Since cells are chemical factories by virtue of the enzymic catalysts which they contain, the origin of such catalysts (all of the contemporary ones being proteins) had to be explained. The spontaneous abiotic production of many kinds of enzyme-like proteinoids has been indicated by experiments; the products have relatively specific behavior, of the kinds found in today's organisms.

3. *The origin of metabolism in the absence of metabolizing cells.*

By association of individual reactions catalyzed by proteinoids, the origin of metabolism can be understood. This demonstration vividly makes the point that metabolism (and other functional properties) of the cell has its roots and its origin in one kind of material. That material was a sufficiently variegated polymer, or polymers, of amino acids.

For such metabolic potential to exist, prior cells were not needed. However, for fullest expression of this potential in specialization, localization in the cell and development of very high levels of activity, the evolutionary process has required the incorporation of such activities into proliferating systems, subject to Darwinian selection.

4. *The origin of cells when no cells existed to produce them.*

George Wald stated in 1954 that the problem of how anything as complex as a cell could have come into existence had often been regarded as "insuperable." Wald also proposed in theory an answer to this question. His answer was based on experiments of F. Schmitt of the early 1950s. These experiments showed that protein molecules contain the information necessary to assemble themselves into subtly structured microsystems. Since the experiments of Schmitt, the general phenomena of *self-assembly* have come to be recognized as widespread and powerful. Wald invoked these in a general way for the first cell.

The experiments with proteinoid are, in a specific manner, consistent with this correlation. They demonstrate that many kinds of polymeric combinations of amino acids, including those produced by heat, assemble themselves into microstructures having a number of resemblances to contemporary cells of the coccoid bacteria. Such features as lipids and nucleic acids, found always as components of contemporary cells, are found not to be necessary as adventitious substances in these units. Both the order conferred by nucleic acids and the selective quality of lipids have been shown to be provided in part by the proteinoid in the assembled structure. Many other properties, such as the enzyme-like activities, are also part of the microsystem, being present through the same modulation from molecules to system of step c.

The properties found and the thorough experiments revealing them are documented in detail in the scientific literature. The assembled systems contain simultaneously, the various properties necessary for primitive life.

What has often been regarded as the most difficult of the problems of protobiogenesis has thus proved to have an explanation of the utmost simplicity. This simplicity is operational, or phenomenological. The intimate structure, molecular or morphological, is however most complex.

5. *The origin of membranes when no microsystems containing membranes existed.*

The proteinoid microstructures have been shown to display double layers which resemble the ultrastructure of contemporary cells, permit retention of large molecules while allowing small ones through, and selectively allow interior proteinoid molecules to diffuse out. These are some of the properties of membranes; the experiments thus illustrate how the origin of membranes could have been intrinsic to the assembly of proteinoid microstructures.

6. *The origin of reproduction.*

Also inherent in the proteinoid microparticle is the tendency to participate in the reproduction of its own likeness. The nature of this sequence of processes seems to be closer, in many respects to that of simple physical phenomena than to the complex concomitance of events associated with contemporary reproduction. Such simplicity, however, is appropriate for the recent emergence of a "biological" type of phenomenon from the inanimate world. On the other hand, these processes are processes of systems and their complexity is such that they were not, and could not have been, predicted alone from knowledge of the behavior of macromolecules.

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During the next two decades, biological research may explore the intimate relationships of biological function to the structure of the related macromolecules and the products of their assembly. A further reduction of biological science to the underlying physical sciences should be achieved in considerable part through the applicaion of constructionistic research (ribosome reassembly, artificial cells, relationships of monomers in polymers to properties of microsystems assembled from the latter).

THE INVESTIGATIVE LABORATORY IN AN INTRODUCTORY BIOLOGY COURSE FOR NONSCIENCE MAJORS AT MARQUETTE UNIVERSITY

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Introductory science course offerings traditionally have a coupled lecture-laboratory organization. Frequently, the laboratory has been used to illustrate material previously introduced in the lecture to teach a multiplicity of techniques which of themselves are of doubtful importance or to illustrate the diversity of living organisms. Because of time limitations, attempts to provide breadth of coverage have so formalized lab work that it is reduced to an exercise in manual dexterity rather than intellectual skill. Students criticize undergraduate laboratories because of the repetition of simplistic exercises, the answers and conclusions of which either elude the student entirely or are understood before the exercise was begun. The laboratory experience has to assume a more meaningful role, especially to the student whose only college contact with science is the one course he takes to satisfy his liberal arts science requirement.

A recent change in Marquette's undergraduate biology curriculum, involving the divorce of laboratories from lectures provided a unique opportunity to introduce a laboratory course in which the student, science-oriented or not, could become familiar with the analytic method of obtaining information. Thus the laboratory would be used to engage the student in the process of investigation.

This approach corresponds to the concept of the Investigative Laboratory as outlined in a 1969 position paper by the CUEBS Panel on the Laboratory (Holt et al., *BioScience*, **19** (12):1104-1107).

One of the roadblocks in introducing the investigative laboratory lies with the individual faculty member who, although interested in implementing changes, has difficulty visualizing how such a program can be established. The object of this paper is to describe the I-lab at Marquette to which some 600-700 nonscience major students are currently exposed annually.

Course Structure

Liberal arts students may satisfy their science requirement by completing eight credits in biology. This is accomplished by taking three one-semester courses: Biology 1 and 2 (lecture courses), and Biology 3, a one-semester laboratory course carrying two credits. Biology 3, offered both fall and spring semesters, has Biology 2 as its prerequisite and may be taken concurrent with or subsequent to that course.

Biology 3 is divided into two parts. The first, consuming about one-third of the semester, is used to prepare students to carry out individual research problems. The remainder of the semester is devoted to independent study on some topic of interest to the individual student.

Introducing Students to Investigation

By and large, college students want and enjoy the challenge of the unknown that I-labs provide. It is the rare student, however, who can be thrust into such a lab and be expected immediately to "start investigating." An introduction to experimental design, laboratory procedures and equipment, and the effective use of library facilities has been found to be a necessary preliminary step to student investigation. Thus laboratory activities during the first part of the course are designed to develop these skills and to give the student confidence in his ability to carry out meaningful investigation.

The first meeting is devoted to a class discussion of an experiment on the effects of gibberellin on dormancy in woody plants.[1] This study is approached as a "dry lab" and includes: (a) background observations; (b) formulating hypotheses; (c) testing hypothesis and setting up controls; (d) collection, analysis and interpretation of data; and (e) suggestion for further studies.

Initially, the class is provided with background information on gibberellins and the phenomenon of dormancy in woody plants. Then, through directed questioning by the instructor, the students attempt to develop a hypothesis relating a possible role of gibberellins to the induction of dormancy as evidenced by a cessation of shoot growth.

Following establishment of a testable hypothesis, questions by the instructor (and not infrequently by students) bring out some of the basically mechanical things that should be considered before proceeding with the experiment. For example:

How many plants should be used? What size plants should be used . . . trees, seedlings, or seeds?

Where should the experiment be carried out . . . outdoors, in the greenhouse, or in special growth chambers?

Where does one obtain the gibberellin? How is the hormone applied . . . spray, injection, or into the soil? How much should be applied?

How often should measurements be made? How should data be collected and recorded? (The value of accurate records and use of a data book should also be brought out.)

How can one be reasonably certain that any effects observed are due to treatment with gibberellin? (This leads into a discussion of the concept of "controls" and the value of statistical analysis in experimental studies.)

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[1] Individual topics may vary from semester to semester although this particular one has proven quite effective.

At the conclusion of this lab, each student is asked to design a hypothetical experiment centering on gibberellin and dormancy and bring it to the next laboratory meeting where individual "experiments" are discussed by the class.

How to use the library, particularly with regard to the use of various abstracts and journals, is provided through a formal audio-visual lecture given to Biology 3 students by the director of the reference section of the main library. A library assignment is then given so that each student has the opportunity to make use of the library facilities. For example, last semester students were asked to write a 200-word summary (with bibliography) on abscisic acid, including studies involved in its discovery and its biological role.

The second laboratory meeting consists of individual presentations and class discussions of the hypothetical gibberellin experiment discussed the previous week. During the last half of the period, students are given 20-week-old bean seedlings and an aqueous solution of an unknown growth substance. They are assigned the task of determining what effect the substance has on the plants. There are no restrictions as to their experimental approach or the parameters used to determine the effect of the chemical on the plants. Students are only informed that the solvent is water, and they are to submit their results in 2 weeks: their paper consisting of a brief introduction; a detailed description of the methods and materials used; and the results, presented in tabular or graph form, or clearly described if consisting of a series of observations. The unknowns provided are gibberellic acid and B-9 at concentrations of 100 parts per million.

Students have come up with a variety of approaches to this study. Some dilute the solution, others use it at the concentration issued. Some spray it on the leaves or inject it into the stems, others remove the plants from the pots and place the roots into the solution. Students not only measure increases in height but determine changes in wet or dry weight. The aproaches used and the parameters measured are as varied as the student population.

At the conclusion of the study, selected experiments are discussed and "constructively criticized" as to experimental design, method of collecting data, and so forth. This "wet lab" has proved to be an effective way to have the student use information from the dry lab and, according to a number of student comments, has added to the student's confidence in his ability to design and carry out a controlled experiment, albeit a relatively simple one.

The third and fourth weeks (the 2-week interval during which the students are working on their "wet" lab study) are devoted to laboratory procedures and basic instrumentation. This includes use of pipets and other volumetric glassware, balances, pH meters, colorimeters, and the preparation of per cent normal and molar solutions. These studies are supplemented by the use of film loops for those individuals who want to spend additional time on specific procedures.

Although we place few restrictions on areas of investigations, we have found that the majority of our students select studies involving bacteria, frogs, tadpoles, chick embryos, and various plant materials. Thus, during the fifth and sixth weeks of this preliminary phase, students are introduced to a few specific techniques in microbiology and developmental biology. For these studies, selected exercises similar to those available as "separates" from some of the major publishing companies (e.g., W. H. Freeman, San Francisco) are used. We have or will use microbiological studies involving the preparation of nutrient media, sterile techniques and methods of incubation, studies on the early development of the frog that involve artificial stimulation of ovulation and fertilization, and studies in which the student incubates chick eggs and examines the developing embryo periodically during its development. Little is done with formal exercises on plant materials at this time since earlier laboratory studies dealt with aspects of plant growth and development.

During the last 2 weeks of this introductory phase, students identify and refine an area of investigation. They may arrive at this point from a number of directions. Some come into the course "knowing" just what they want to investigate. Some have ideas or questions generated as a result of the formal laboratory studies. Others become interested in an area after examining "bound" copies of student investigations carried out in previous semesters.

Active Investigation

Regardless of where or how individual students become interested in a topic to investigate, the questions they ask are frequently much too broadly defined and need to be narrowed considerably. This is done through individual conferences with the instructor either during the laboratory hours or during scheduled office hours. This is a time-consuming activity since each instructor is essentially tutoring 60-75 students; each teaching assistant handles 25-35 students. This aspect of the course is critical and no student is permitted to begin his study until he has submitted a proposal that includes the question he is asking, the rationale leading to his study, a tentative hypothesis, and a brief statement of materials needed and the approach to be taken. A bibliography, citing references to similar studies, must also be included. Once his proposal is approved, the student is no longer bound by formal laboratory attendance. He is, however, required to meet biweekly (or oftener if desired) with his instructor to report on his progress (or lack thereof). Records of these meetings are kept by each instructor. This apparent contradiction to open labs accomplishes the following:

1) It provides time for the instructor to become familiar with the student's project. The need for this becomes more apparent when the project has to be evaluated,
2) It presents an opportunity for questions, by the student as well as instructor, regarding any problems in techniques, interpretation of data, and so forth; and,
3) It is a device (unfortunately needed) to protect the instructor from the small number of students that "disappear" and then either claim they never had anyone available for help, or turn in a report suspect in its professionalism.

Some students do not need these conferences. Such students, however, are found to have no objection to this requirement and indeed use it to their advantage.

Approximately 10 weeks are devoted to individual study, with the last 2 weeks set aside for the reporting of results in a paper patterned after the standard format of most scientific publications. Titles of some of the studies undertaken by students in past semesters are listed at the end of the article. It should be noted that no student is penalized if he fails to get "results" through no fault of his own. Indeed, some become so involved in working out techniques that the course ends before they have generated any data. (The value of the biweekly conference becomes apparent in this situation.)

Final grades in the course are based upon three criteria, weighted as follows: 20% is given for the initial design and originality of approach; 30% is given for effort, interest, and persistence in solving difficulties during the course of the study; and 50% is assigned to the paper and is based upon attention to format, clarity of writing, a discussion that includes relationship of the study to published data or to the results of classmates carrying out similar studies, and so forth.

Logistical Problems

A course such as this presents some minor problems in areas involving space, assignment of equipment, and procurement of materials.

Space: We routinely schedule 12-16 laboratory sections per semester, with an enrollment of 20 students per section. Because of the open laboratory aspect of the course, two rooms have proven to be adequate space for the number of students involved. Indeed, because there is no absolute requirement that the investigation be carried out in the teaching laboratory, we have fairly large numbers of students working outside of the labs. Examples follow.

Several students, interested in the detection of coliform bacteria, contacted the health department laboratories. The staff willingly worked with these students and appraised us of their performance.

Two students who wanted to investigate the effects of ethylene on plant growth contacted the plant physiologist on our staff for advice. During their discussion, they became more interested in a growth factor he was involved with and ended up working under his direction.

Others interested in immunology were provided space in a research laboratory and were guided by a graduate student majoring in this area. This student, also a teaching assistant in Biology 3, provided advice and assistance in studies involving selected immunological techniques.

A fairly large number, 65-70 students, were provided bench space in the greenhouse for studies on plant growth and development.

Approximately 35-40 students who elected to work with bacteria were located in an unused prep room and provided with a hood, incubator, and other basic materials needed for culturing bacteria.

A small number of medical technology students carried out studies in cooperation with the staff of the medical school, and in some cases, hospital laboratories.

One student, a psychology major, obtained the advice and guidance of a faculty member in that department.

A number of other students, even though working in the teaching labs, contacted and received advice and encouragement from various faculty members in the department. Indeed, this type of course provides a unique opportunity for faculty to become "visible" at a time when students are seeking greater faculty-student contact.

Equipment: Specialized equipment, e.g., microscopes, waterbaths, colorimeters, pH meters, etc., are signed out to individual students by the equipment supervisor. At the time equipment is issued, each student submits a card, signed by his instructor, indicating the equipment needed. This card has space for the student's name and signature, home and school address, university identification number, and the room where the equipment will be used. These cards are kept on file until the equipment is returned. Once issued, the equipment is kept in a locked cabinet in the teaching laboratory. The student may obtain the equipment by asking any instructor to open the cabinet. All equipment is signed out each time it is used, thus providing us with some control of equipment use and movement, and assuring the student that his equipment will be available when he needs it. Although we have not had to resort to it, grades are held back for equipment not returned at the end of the semester.

Chemicals: Standard laboratory reagents are kept in each laboratory. These include the more common carbohydrates, amino acids, nutrient media, plant growth substances, animal hormones, various vitamins, salts that comprise basic culture media, etc. The amount and kinds of chemicals routinely stocked is based upon the needs most often expressed by students in previous semesters. Specific needs by students are checked against chemicals on hand and are ordered if not in stock.

Live Materials: Each student is responsible for maintaining living materials used in his study. We have found, especially with respect to planaria, hydra, various algae, and other organisms requiring special handling, that it is advisable to have the student become familiar with culture conditions before ordering this material and that he demonstrate his readiness to receive and maintain the organisms when they arrive. Directions for handling such cultures can be provided in the laboratory as part of a "Culturing Technique" book. Most living materials can be made available to the student within a week to 10 days after his needs are known. A list of the students, including materials ordered and tentative delivery date, is posted near the laboratories so that each student will know when his materials are expected to arrive.

Staff: The course is presently staffed by two faculty instructors (one M.S., one Ph.D.), two graduate teaching assistants, and a senior Biology student who has miscellaneous duties. We have been fortunate in that the student currently helping us looks upon his work as more than a job. He has involved himself in planning, made excellent suggestions for improving various aspects of the course, has signed up for time on the University's computer and takes interested students over to use it for statistical analysis of their data, and has provided excellent feed-back from students as a result of his being a dormitory counselor.

One might suspect that a course such as this is demanding of both instructor and student time. It is. Our instructors feel that for the first time they are really getting to know the strengths and weaknesses of their students because of the personal contact this type of course promotes. And even though the contact hours spent exceeds those of the more traditional laboratory, they would not want to revert to the previous, more formal laboratory organization.

We fiind that students, even though spending about twice the amount of time in the laboratory, are generally enthusiastic.

Typical of the comments received on a course evaluation are those given below:

"I like the fact that it is mostly an individual course. Perhaps this is what allows it never to become boring."

"It makes the student take on more responsibility. It is a good exercise in working with people."

"I don't know about anyone else, but I got all excited about my experiment and felt I learned something."

"I complained a lot about this course but I can honestly say I got something out of it. A Liberal Arts student, no matter what field he is going into, will someday have to think for himself."

"To Liberal Art's students who'll never pass this way again it should be a good remembrance of hard work."

In conclusion, students are asking colleges and universities to provide courses uniquely different from their high school courses. The I-lab approach provides the sciences with the opportunity to offer such courses.

Some Investigative Studies Carried Out by Students in Biology 3, the Introductory Laboratory Course

1. The effect of crowding on planaria.
2. Toxicity studies of Malathion on *Drosophila* larvae.
3. The effects of calcium cyclamate on the developing chick embryo.
4. Resistance of *Escherichia coli* to streptomycin following U-V irradiation.
5. The effects of acetyl choline on classical conditioning in *Catostomus* sp.
6. The effect of proflavine on the development of chick lens.
7. Responses of planaria to shock.
8. The effect of light on learning rate in mice.
9. The effect of proflavine on regeneration in planaria.
10. Osmoregulation in *Catostomus commersonnii.*

AN INTRODUCTORY INVESTIGATIVE LABORATORY AT A TWO-YEAR COMMUNITY COLLEGE

John W. Thornton
CUEBS, Staff Biologist

At a time when elementary and high school science curricula are stressing the importance of teaching the processes by which science grows, it is discouraging to note how few introductory college biology courses actually provide an opportunity for students to receive experience in using those processes. The absence of effective science laboratory programs in teacher training curricula is particularly distressing. In an effort to provide some guidance for reform in this important area, CUEBS has challenged teachers to experiment with the development of Investigative Laboratories (*BioScience*, **19** (12): 1104-1107). Carol Paulis and Agnes Wilhelm of Catonsville Community College, Catonsville, Maryland, responded to this challenge and are offering the introductory investigative laboratory course described below. As a staff biologist for CUEBS, I recently visited and evaluated their program. The following article describes and evaluates that program.

Vital Statistics

Biology 104, Laboratory Studies in Biology, is a separate laboratory course which is offered for 1 or 2 hours of credit. Many of the students enrolled in Biology 104 are concurrently taking a course Principles of Biology (Biol. 103). Most of the students are not pursuing a biology major but the course serves as an elective in their curricula. Enrollment is limited to 24 students per section, with the number of sections varied to accommodate the demand. All sections are taught by Mrs. Wilhelm, although Mrs. Paulis was involved in planning it.

Course Structure

The course is divided into two phases: the first being carefully planned by the instructor to prepare students for independent investigation; and the second left unstructured to permit each student to carry out an investigation of his own choosing. In phase one, students attend a regularly scheduled, 3-hour laboratory period each week during which they discuss the investigative process, learn to locate library resources, see demonstrations of selected techniques, and carry out exercises in which they collect and analyze data. They are made aware from the beginning that this is to prepare them for independent investigation.

Although it is anticipated that the exercises used in phase one of the course will be varied from semester to semester, those currently being used include a "dry" (talk through) laboratory on gibberellins and "wet" laboratories in which students observe living chicken embryos at different stages of development, isolate and culture soil microorganisms, identify some of the living components of a natural ecosystem, study the effect of an introduced chemical or physical factor on the structure of an artificial microecosystem, assay for the presence of enzymatic activity in egg albumin, and analyze the effects of physical and chemical variables on the rate of enzymatically catalayzed reactions.

Many of these are similar to the open-ended exercises currently described in laboratory manuals prepared for introductory courses in biological principles. These activities are designed to provide students with insight into investigative processes and to build confidence in their own ability to carry out meaningful investigation. To achieve these objectives, the instructors use inquiry and problem-solving approaches. A list of questions designed to evoke student analysis of the investigative processes is distributed each week. Discuscussions built around these questions and the concrete laboratory experiences of the students are also a part of each week's activities. Judging from the comments of students and their performances during the second phase of the course this carefully planned mix of questioning, laboratory work, and discussions seems to do an excellent job of preparing them to play the role of an investigator.

By the third or fourth week of the semester most students have identified a general area in which they wish to carry out an investigation. The following table of contents of the student-produced journal indicates the topics chosen during one semester.

THE CATONSVILLE COMMUNITY COLLEGE JOURNAL OF BIOLOGICAL RESEARCH
Established 1970

SEPTEMBER

Volume I — Contents — Number 1

In many instances, the area of investigation is chosen on the basis of experiences which the student has had outside the course, while in other cases the open-ended laboratory exercises have captured their interest.

By mid-term, students must submit a proposal of the investigation they wish to pursue. This proposal states the questions for which answers will be sought, states hypotheses, and describes techniques. Materials, equipment, and supplies which will be needed are specified and references to previous studies on the topic are cited. The proposal is presented by each student to the class for criticism.

According to the instructors, it has not been necessary to artificially limit the areas which may be investigated, but the natural constraints of time, money, space, and ability tend to provide natural limiting factors which keep the proposals within the "reasonable" range.

After the proposals have been approved, the class does not meet, formally, until the end of the semester. The laboratory is left open for student use and the instructor is available for consultation. If students are working outside the laboratory (home, field, etc.), weekly progress reports are required. In spite of the absence of formal class meetings during this period, instructors report significant exchange of ideas and information among students and between students and themselves. This exchange seems to be catalyzed by the genuine interest which the participants in the class have in their own and other's projects. The obvious interest and enthusiasm by the instructors, is, of course, an important factor in stimulating this exchange.

During this phase of the course, the instructor also schedules an extended, individual tutorial session with each student. In this session, all the work submitted by the student during the first phase of the course is reviewed and a detailed discussion of his project ensues. The instructors report that this session is particularly helpful for those who are shy or hesitant to seek help.

The course terminates with a symposium in which each student presents a brief résumé of his project. A written report, using the format for a scientific paper, is submitted. These are ultimately published in the *Journal of Biological Research*, an in-house publication created specifically for this course.

Evaluation

The objective of the course is to teach students to understand and appreciate the investigative process which gives rise to biological knowledge. Since the objective is stated in nonbehavioral terms, it is probably not possible to quantitatively measure the success of the program. Based upon my interviews with the students involved in the program, however, the course must certainly be given high marks for effectiveness. In addition to achieving its stated objectives, the course seems to have accomplished the following worthwhile ends:

1) *New knowledge*. Although few, if any, of the student papers would meet the standards for publication in national professional journals, they do represent a much greater contribution to our knowledge than the repetitious laboratory reports typically produced by undergraduates in general biology courses.

2) *Personal development*. The instructors teaching the course feel that the investigative approach contributes much more to the students' intellectual growth than did the previously used exercise approach. Both instructors and students report that the emphasis upon individual projects decreases cut-throat competition for grades, increases cooperation between students, and improves student-faculty rapport. As with almost any course taken by freshmen, this one seems to aid some in making a career choice. Students seem to think the course was particularly helpful in this regard because it gave them insight into what biologists actually do in their professional work. For example, one student commented: "I think the course was an excellent one, for it forced me to think about the process of science and taught me how to use the scientific approach in trying to answer questions. This may cause me to change my major."

Some students also believe that the course may have been influential in changing their general life style from one in which they blindly accepted what authorities told them to one in which they feel a need to look for evidence and investigate problems on their own. If the course can be credited with such a change, it has indeed been effective.

There are, of course, some difficulties created by the course and areas in which the students and instructors recognize the need for improvement. The 1 or 2 hour credit which is assigned to the course does not adequately reflect the amount of effort expended by students and faculty. During the second phase of the course, it is not at all uncommon for a student to spend several hours each day on his investigation. In some cases, this may detract from other studies. For example, one student had to be locked out of the laboratory so that he would not spend all his time on his investigation and, as a result, fail in his other courses. Students do not object to spending considerable time in the laboratory, but feel that the course credit should reflect their effort more accurately. Three or four hours of credit could probably be justified for most students.

The time spent by the instructor is also extensive. Teaching three sections of the course easily consumes all of the instructor's time. Calculation of the teaching load on the basis of student credit hours or official contact hours does not give adequate recognition to the amount of faculty time actually spent teaching the course.

Finally, if unexpected problems are encountered during the investigation, there may not be sufficient time to redesign or repeat the experiments or observations. Faced with the inflexible deadline imposed by the school calendar, these problems can be extremely frustrating for students. Students encountering such problems are, of course, advised that this is to be expected in any worthwhile investigation. They are encouraged to report their partial results and are assured that they will receive a good grade if their report indicates that the investigation was well planned. Even so, such students are robbed of the self-fulfillment which comes from carrying an investigation to the point at which conclusions, based on data, can be drawn. An arrangement which would permit students to enroll for additional credit and continue their investigations in a subsequent semester might provide a partial solution to this problem.

In spite of the difficulties encountered and hard work required, I find that the approach being used to teach the beginning biology laboratory at Catonsville Community College is a significant improvement over the traditional exercise approach currently used in so many colleges and universities. The success indicates that the investigative approach is feasible for two-year colleges which typically have modest resources and faculties who lack extensive research training and experience.

BIOLOGY FOR PHYSICISTS: TWO VIEWS ON WORKING PAPERS NO. 2*

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A recent addition to the new series of occasional publications, the CUEBS Working Papers, reports belatedly on a conference in November 1968 of members, friends, and employees of three college commissions to discuss ways to bring physics and biology closer together in the early undergraduate years. Co-sponsored by the Commissions on Education in Agriculture and Natural Resources (CEANAR), on College Physics (CCP), and on Undergraduate Education in the Biological Sciences (CUEBS), the conference was convened at O'Hare Inn near Chicago, under the chairmanship of Arnold Strassenburg of the American Institute of Physics, with the specific charge of outlining ways in which the value of the physics courses commonly required of biology, agriculture, and natural resource majors could be made more readily apparent and their appeal for this diverse group of biology and near-biology majors could be increased.

The conferees quickly rejected the suggestion, presented in the pre-meeting rationale, of paperback monographs containing mature and sophisticated examples of physical principles at work in the biological sciences, but they agreed on making instructors of introductory physics the target audience. The group outlined a concept of separate "vignettes" which would enable these instructors to become familiar with a wide variety of biological applications of physics. The bulk of the meeting was then devoted to filling in details, listing appropriate topics and potential authors, and outling steps in implementing the idea. The group envisioned a modular format for the vignettes. In a preliminary statement, a typical vignette would provide a condensed and integrated view of the concept (e.g. turbulent flow of liquids in tubes). It would then sketch the basic arguments used in developing a quantitative physical-mathematical treatment of the topic and proceed through a series of examples which would "show how thoroughly sophisticated applications of the concept could be made to real problems in biology and agriculture."

As should be expected when physicists and biologists get together, agreement was difficult to achieve on such things as the rigor of physical definitions, the extent of biological explanations, the importance of problem sets, and the value of concluding remarks aimed at shifting the reader into an inquiry mode. There was unanimous and enthusiastic feeling, though, that it would be good to get several such vignettes in hand, illustrating different views, perhaps, in the mix of quantitative rigor, biological background, and problem-oriented or inquiry-oriented examples.

November 1968, you may recall, was a few weeks after the axe fell on many NSF-funded projects, and the intended follow-through on this conference, was one of the many things that had to be sacrificed. The need remains, however, and though the participants in this meeting appear to have moved off in other directions, the idea and a touch of the original enthusiasm remain visible within the report—waiting, obviously, for a new champion, a new time.

Care to have a look, or to give it a try? The report is available from CUEBS.

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Many undergraduate biology students often ask themselves why some science courses are required which they later rarely use. In many cases these questions are probably warranted. Unfortunately, courses which should prove useful, such as introductory physics, are often questioned. If basic physics is useful and applicable to biological problems, as I believe it is, then why doesn't the student make better use of it in his work?

This question obviously received serious consideration from CUEBS during a 1968 conference as reported in Working Paper #2, published in June 1970. The conviction of the conference members that opportunities for interchange between biology and physics do exist on the introductory level is true. Their recommendations that interchange be promoted by adding more biology to introductory physics by illustrating physical principles with biological examples should be one effective approach.

However, even after presenting biological problems illustrating the physical approach, there are additional, perhaps even more serious, barriers to the effective use of physics by biologists. From my own experience, there seem to be at least two difficulties either neglected or only casually referred to in the working paper.

The first difficulty arises because physicists and biologists reason differently. This point can probably best be illustrated by considering what a physicist and a biologist mean by "understanding." When a physicist says he "understands" a point, he means he can relate it to the appropriate fundamental physical principle. For example, a specific solution to a problem in mechanics can be derived or defined from Newton's laws of motion. A biologist, on the other hand, usually means he can visualize or logically reason through to the solution in terms of his own observations and experience. By this I do not mean the biologist never bases his reasoning

* Abell, D. L. (Ed.) 1970. A working conference on source material in physics-biology-agriculture and natural resources. CUEBS Working Papers No. 2, 19 p., processed.

on fundamental principles. The pervasive use of the theory of evolution in biological reasoning would refute this. But biology at present simply does not have a rigorous theoretical foundation as does physics. Of necessity, many fields of endeavor in biology are composed of collections of observations with few underlying general principles.

The basic reasoning and power of generalization in the physicist's approach is too often inadequately emphasized in the introductory physics course and is not fully appreciated by the biology student. The student then has a tendency to view a specialized equation or conclusion as an isolated observation without realizing it is a special case of a more general principle. The student must realize that in biology we have our own special conditions for special problems. These problems are often open to physical analysis, but to be effective the analysis must proceed from first or intermediate physical principles to the special biological case with consideration of the special conditions involved. A simple example is diffusion of some substance (e.g., CO_2) from a cell. Any analysis will start with the fundamental diffusion equations. These equations would then be modified to account for cell geometry (e.g., spherical or cylindrical cells). An additional consideration might be rate limited diffusion at the cell surface. For the physicist, these considerations would probably be sufficient to solve the physical problems he might have. However, the biologist may want to consider additional factors such as changes in permeability of the cell surface and rate of CO_2 production. In order to solve the wide variety of biological diffusion problems, a biologist must be capable of reasoning from fundamental diffusion equations and accounting for the special conditions in each problem. In short then, to use physics effectively, the biologist must realize that new and unfamiliar patterns and processes of reasoning will be necessary; and a real effort should be made by the instructor to emphasize this point.

The second difficulty arises from the actual process of working from the first principles to a final solution of a problem, a process which, in physics, depends very heavily on mathematics. The concise language of mathematics is certainly more familiar and convenient for the physicist, but most biology students are uncomfortable with a strict mathematical treatment even if they have had relatively advanced mathematics courses. The student will often content himself with learning the formulas and plugging in the numbers without struggling with derivations and details of the argument. The student should understand that the ability to derive a solution is usually necessary for problem-solving. As pointed out in the previous example on diffusion, it may be necessary to derive a new solution for each special problem.

Recognizing the importance of derivations, it would be undesirable and unwise to eliminate most mathematics from the introductory physics course, but the physics instructor could supplement some of his derivations and problem-solving with a thorough explanation of just what his mathematical expressions and treatments mean. This accompanying verbal explanation should greatly assist the biology student in working his way through a mathematical argument.

Just how effectively these two points could be included in the modular approach recommended by the conference members is uncertain. They would probably be more difficult to implement than the addition of biological examples, since a change in teaching rather than the addition or substitution of material would be necessary. The burden of effort would be on the instructor to devise a new teaching approach, although he could be greatly assisted with adequate "vignettes." The biology department alone might arrange weekly discussion and problem-solving sessions to assist biology students taking physics and discuss the "biological viewpoint." Closer cooperation between biology and physics departments for planning physics instruction for biology students might also provide more effective ways to implement the suggested changes. Whether instructors and departments would be willing or capable of making such changes in instruction is uncertain, but it is my opinion that the changes should be made.

*see article by Joan Creager, p. 14

THE THREE I's

Interdisciplinary, Investigative, and Independent Study

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For years I had heard graduating seniors speak unhappily of their education ("I still don't know who the hell I am," "I still don't know what I want to do with my life," "I don't even know if such questions matter to me any more") and express bewilderment at how eager, curious freshmen had been turned, four years later, into prototypes of articulate emptiness.

—Martin Duberman, *The Uncompleted Past*

I's. Why I's? Perhaps because *Homo sapiens* are universally egocentric. As the psychologist Alfred Jones said: "I never met a man who wore his ego on his periphery." Or, perhaps those indicative parameters of the deficiencies of contemporary higher education so incessantly reiterated: incredibility, impersonalism, and irrelevance. Or, facetiously, the McLulanesque "eyes" liberated from the perceptive chains of linear typography.

The three R's have predominated most educational approaches from kindergarten through graduate school. Pedagogy has concentrated on the acquisition of communication skills, i.e., reading, 'riting and 'rithmetic, but sadly the instruction has been used to indoctrinate with "facts" to be regurgitated, to inculcate *status quo* attitudes, to stifle imagination, and to cure insomnia. If higher education is to quell rising student dissatisfaction and faculty discord, the first effort must be to seek viable alternatives to didactic delivery methods in order to promote a resurgence of intellectual atmosphere on campus. This note suggests the use of three educational approaches which have been used successfully in experimental situations and which now deserve widespread utilization.

No, the triumvirate educational panacean paradigms we seek are not id, ego and superego or any of the other aforementioned I's. Instead, the supposition purported here is that INTERDISCIPLINARY, INVESTIGATIVE and INDEPENDENT study are the *sine qua non* for a better undergraduate curriculum.

The recognition of the importance of interdisciplinary study has been rapidly evolving. Robert H. Rimmer's *Apology from a Man in Search of a Fulcrum* states: "The purpose of undergraduate education is integrating the whole man into a value structure that helps him realize himself as a human being." Let me accentuate the integrative aspect. Koestler believes this is one of the single-most important aspects of creativity. Graubard, the historian of science, reminds us that whether the issue is race, mathematics, or knowledge per se, integration is infinitely more difficult than differentiation. Thus at this watershed of history with its prized overspecialization, it has become imperative for undergraduates to be released from the tunnel vision of some mentors. Ecology stresses interactions of all components of the system. A search for identity among students of this era must stress how intricately and inseparably intertwined are all aspects of human knowledge. The dichotomy of the "two cultures" can no longer be tolerated.

Investigative study or the inquiry approach is heralded due to the fact that it is student-oriented. Students cannot be inimical on the basis of irrelevance because the approach enhances their innate curiosity. This approach has been nicknamed somewhat appropriately as a "subversive activity" by Postman and Weingartner. More importantly, the investigative method releases the student from his passive classroom role. In the CUEBS report on investigative laboratories, Woodward praises them on the analogy of comparing cookbook labs to calisthenics and investigative labs to scrimmages; scrimmages are enjoyable because they are more akin to the real game. Thus, justifiably, investigative students feel more immersed in the process of acquisition of new knowledge and are given more opportunity to self-actualize in the process.

Independent study has met with more opposition than either of the previous two combined.

A spurious situation has evolved where students in abject ignorance supposedly can dictate to universities by threat of strike. Although student cooperation in decision-making is essential to the development of more realistic education policies, the use of "strikes" is an anachronism. These student bellwethers have subjugated themselves to the position of employees and hence are inimical to upgrading of the role of the students. Students need to realize their right to "boycott." Widespread use of independent study would involve the student to greater personal extent than the traditional other end of the log. Responsibility will breed maturity. If professors and administrators feel they must perpetuate *in loco parentis* in all aspects of parietal life, then the concomitant obsequious mediocrity or ridiculous radicalism of typical student behavior is bound to continue.

The inevitable absurdities of this approach to maturing intellectuality reveal readily why we are at the confluence of academic history.

The long-standing argument against independent study is hence seen as a tautology. "Students are too immature, too impressionable and too irresponsible to be left to their own devices." However, on the other hand, if students are never required to assume responsibility for their own education, then how can we expect them on graduation from such a cuddled atmosphere to transcend these limitations? Students must recognize their customer position. The rewards of education should be somewhat proportional to the initiative and imagination displayed by a student.

The intangible, idiotic ideas of radical students are mere platitudes, not panaceas. The cryptic deficiencies of mentors preparing future teachers are bound to impede progress. Students cannot be programmed to acquire the essential body of facts necessary to become scholars. A little individual introspection on the part of professors would indicate that their scholasticism is due to a process; i.e., a scholarly approach to the creation of new knowledge. The three I's are processes; the three R's are skills.

The author being an impudent student himself with all the inherent inadequacies has thus promulgated his views with invectives, insults, and invidious inferences. In spite of these, it is gratuitously implored that readers might have gained some miniscule insight into student insistencies. Even if you completely disagree with us, insipid, insouciant replies will only polarize us further. The decision to be made rests on one question: Will academia encourage undergraduates to play a more responsible role in their own education?

REFLECTIONS ON A VISIT TO THE MINICOURSE PROJECT AT PURDUE

Joan G. Creager
CUEBS Staff Biologist

The primary purpose of the Minicourse Project at Purdue is to develop a set of minicourses which deal with all of the essential concepts that might be expected to appear in the basic core of biology. Dr. S. N. Postlethwait is director of the project and Dr. Frank Mercer, formerly of University of New South Wales, is co-director. Some of the other staff members I talked with in January 1971 include Mrs. Jan Mercer, who has an interest in minicourses for nonbiology majors, and Dr. Jim Russell, whose interests are in educational technology, especially in the area of programmed instruction for groups of students.

The minicourses are currently in various stages of development, from those that are only an idea to those that are set up for evaluation by staff members and students. Each minicourse will have certain instructional objectives and the materials necessary to accomplish these objectives will be provided. The presentation will be preplanned so that the student will be led through the minicourse in a logical sequence and will be provided with all the necessary equipment. Upon the completion of all the activities provided in the minicourse, the student should have mastered the content at a specified level of competency.

The emphasis on mastery may be one of the most significant aspects of the minicourse. The aim is to determine what the student should master on the basis of his expressed career goals and to follow through on this so that the student actually demonstrates that he has mastered what he set out to learn. In reflecting on the ramifications of mastery learning, I am reminded of a comment made in Postman and Weingartner's recent book, *Teaching as a Subversive Activity*, in which they compare the teacher who says, "I taught it to them but they didn't learn it," to the salesman who says, "I sold it to them but they didn't buy it." From what I observed at Purdue, students are "buying" minicourses.

In order to get credit for the course, students must master the required number of minicourses. They can take as little or as much time as they need. With the audio-tutorial set-up at Purdue, the student makes the decision as to when and how he will do the work. It is ironical that the major criticism leveled at this approach is that it doesn't discipline the student nearly as well as telling him when to come to class. Rather, it seems to me that the student must demonstrate self-discipline to master each of the minicourses at a "C" level or better and to plan his own time so that he gets the job done.

The use of minicourses will, of course, include college students on the Purdue campus. Minicourses will be exportable to other colleges and by mail to extension students, even those living hundreds of miles from main campuses. They could also be available to laymen interested in independent study irrespective of intention to earn college credits. Through the use of modularized instruction, the rigidly compartmentalized life style of education, employment, and retirement might gradually be obliterated.

Dr. Postlethwait's interest in individualized instruction goes back a number of years to his original audio-tutorial program in botany. The current version of this course is still in operation and the companion course in zoology, under the direction of Dr. Robert Hurst, is also presented in audio-tutorial style. Both courses consist of a set of minicourses, some of which are required and some of which are optional. Students taking these courses may be majoring in biology, an agricultural discipline, or in liberal arts, where a year of science is required.

Although all of the minicourses I observed in operation use the audio-tutorial approach, Dr. Postlethwait assured me that he views "audio-tutorial" as a means to an end and that other modes of presentation might be used in the project. The students I observed in the learning center seemed intent on what they were doing and frequently engaged in discussion with other students or with the teaching assistant on duty. I went through parts of two minicourses myself, much as the student would do, and found that there is indeed a feeling of active participation and personal involvement which I rarely experienced as a student taking notes in a formal lecture. In the quiz section I visited, the students did indeed demonstrate mastery of the concepts they were asked to discuss. Although they were being graded on their presentations, the atmosphere was relaxed and the discussion was free and lively.

Purdue offers another two-semester course in introductory biology which is part of the "core" program. Most of the "core" courses are apparently taught in a more traditional manner, although efforts are being made to encourage more extensive use of minicourses. A special section of the introductory course is offered to nonscience majors. It does not require a laboratory and is devoted to the social implications of biology. Dr. Al Chiscon, who created the course, uses a variety of media in the formal weekly lectures. There are a number of small discussion groups to encourage students to explore contemporary problems related to biology. In addition to the extensive reading list, newspaper items are collected and distributed, thus assuring that students become aware of and informed about current topics. Since the enrollment was expected to be about 60-70 students but now stands at nearer 600-700, it appears that the course is well received by the students.

Other courses which are modularized to some degree and which make use of audio-tutorial methods are Dr. Postlethwait's graduate course in botany, an environmental biology course, a course for secondary and elementary science teachers, and a course in structural biology which is part of the "core." In the portion of the structural biology taught by Dr. Mike Forman, the audio-tutorial approach is used.

One quality that stands out among the members of the Purdue staff whom I met is their concern for other people—for each other and for students. One of their main goals is expressed on a poster: INVOLVE THE STUDENT! And they do.

ANNOUNCEMENTS

Three summer programs for college teachers have been announced by the National Science Foundation. Directories listing the institution offering the various programs may be obtained by sending a postcard to: College Teacher Programs, National Science Foundation, Washington, D. C. 20550. Inquiries and requests for application forms should be addressed to the project directors. Participants are chosen by the project directors, NOT by the National Science Foundation.

A description of each of the programs, and a list of those of interest to biologists, follows:

Summer Institutes and Short Courses

During the summer of 1971 more than 2800 teachers from colleges, universities, junior colleges, and technical institutes will attend summer institutes and short courses in 31 states, the District of Columbia, and Puerto Rico at 69 colleges, universities, and research institutions.

The summer institutes, which range in duration from 4 to 12 weeks, explore in depth a particular subject area that has become significant for the reorganization and strengthening of the college curriculum.

Short courses, on the other hand, are designed to provide specialized training, in recent scientific developments of great importance. Lasting up to 4 weeks, they are conducted by creative scientists. A number of short courses are designed to bring about innovation in selection of subject matter and in the method by which it is presented.

Examples of such innovative short courses include:

At Purdue University, Dr. Samuel N. Postlethwait will present principles of audio-tutorial systems and development of minicourses with supporting materials in interdisciplinary areas. Professor Raymond S. Sleeper of the Department of Cybernetics at the University of Tennessee will analyze socio-economical problems related to an air transportation center. At the University of California at Davis, Dr. Donald G. Lindburg will present a short course on primate behavior. Dr. Ben A. Green at the Massachusetts Institute of Technology will give a short course in the preparation of administration of self-paced and student-tutored college courses.

Summer Institutes

Director and Location	*Topic*	*Dates*
Dr. Gordon L. Bender Department of Zoology Arizona State University Tempe, AR 85281	Desert Biology	June 21- July 31
Dr. Roy M. Johnson Department of Botany and Microbiology Arizona State University Tempe, AR 85281	Bacterial Ecology	June 14- July 23
Dr. David L. Jameson Department of Biology University of Houston Houston, TX 77004	Population Biology	June 1- June 30
Dr. Herminio Lugo Lugo Department of Biology University of Puerto Rico Rio Piedras, PR 00931	Marine Biology and Tropical Ecology	June 21- July 30

Dr. John H. Phillips, Jr. Hopkins Marine Station Stanford University Pacific Grove, CA 93950	Marine Biology	June 14- August 21
Dr. Raymond J. Seeger School of Philosophy Catholic University of America Washington, D.C. 20017	Topics in the Sociology, History, and Philosophy of Science	June 14- July 23
Dr. J. Forbes McClellan Department of Zoology Colorado State University Fort Collins, CO 80521	Field Biology	June 14- July 24
Dr. Ralph E. Lee Computer Center University of Missouri Rolla, MO 65401	Computer Science	June 7- July 30
Dr. Gene A. Kemper Department of Mathematics University of North Dakota Grand Forks, ND 58201	Computer Supplemented Instruction	June 14- August 6
Dr. Loren G. Hill Department of Zoology and Dr. Paul G. Risser Department of Botany University of Oklahoma Norman, OK 73069	Systems Ecology	June 5- July 31
Dr. Graham M. Campbell Department of Computer Science (Write: Dr. Alvin R. Grove 214 Whitmore Laboratory) Pennsylvania State University University Park, PA 16802	Computer Science	June 28- August 26

Short Courses

Director and Location	*Topic*	*Dates*
Dr. Burton J. Bogitsh Department of General Biology Vanderbilt University Nashville, TN 37203	Histochemistry	August 2- August 21
Dr. Arthur Kelman Department of Plant Pathology University of Wisconsin Madison, WI 53706	Plant Pathology	June 13- June 26
Dr. L. K. Akers Special Training Division Oak Ridge Associated Universities Oak Ridge, TN 37830	Applied Ecology	August 16- Sept. 3
Dr. H. Gray Multer Department of Geology Fairleigh Dickinson University and Dr. Malcolm P. Weiss Division of Geology Northern Illinois University at Fairleigh Dickinson University Madison, NJ 07940	Modern Carbonate Sediments and Related Carbonate Rocks	June 6- June 17
Mr. Geoffrey I. Gleason Special Training Division Oak Ridge Associated Universities Oak Ridge, TN 37830	Radiation Sciences	August 16- Sept. 4
Dr. S. N. Postlethwait Department of Biological Sciences Purdue University Lafayette, IN 47907	Audio-Tutorial System of Instruction	June 21- July 16

Research Participation

This year approximately 400 college teachers out of the more than 1200 teachers who are expected to apply, will participate in the program. Support is provided through 71 grants to 51 institutions in 28 states and the District of Columbia.

The primary objective of the program is to strengthen the participant's effectiveness as a teacher by providing firsthand knowledge of how science changes through research projects. Following the summer courses, the most active and effective teachers will be selected by project directors to receive support to continue their research part-time at their home campuses.

This program is one of the Foundation's College Teacher Programs which together provide annual opportunities for about 3000 teachers from 1200 colleges and two-year colleges to update their knowledge and improve their ability to reach college students. The pattern of college teacher participation correlates with state populations and with the geographic distribution of science and engineering teachers.

Director and Location	Projects in	Level	Dates
Dr. Shelby A. Miller Center for Educational Affairs Argonne National Laboratory Argonne, IL 60439	Biochemistry, Genetics, Microbiology, Physiology, and Radiation Biology	Postdoctoral	May 15- September 15
Dr. Allan H. Roush Department of Biology Illinois Institute of Technology Chicago, IL 60616	Biochemistry, Microbiology and Physiology	Predoctoral, Postdoctoral	June 7- August 13
Dr. J. R. Porter Department of Microbiology University of Iowa Iowa City, IA 52240	Bacteriophage Genetics, Immunology, Medical Mycology, Microbial Physiology and Metabolism, Pathogenic Microbiology, and Virology	Predoctoral, Postdoctoral	June 7- August 14
Dr. L. M. Bartlett Department of Zoology University of Massachusetts Amherst, MA 01002	Cell Biology, Ecology, Embryology, Ethology, Parasitology, and Physiology	Predoctoral, Postdoctoral	June 1- August 31
Dr. Robert J. Lowry Department of Botany University of Michigan Ann Arbor, MI 48104	Descriptive and Experimental Botany	Postdoctoral	June 28- August 21
Dr. H. Bradford Craig School of Agriculture and Life Sciences North Carolina State University Raleigh, NC 27607	Agronomy, Animal Husbandry, Biological and Agricultural Engineering, Botany, Entomology, Food Science, Genetics, Horticulture, Plant Pathology, Poultry Science, and Zoology	Predoctoral, Postdoctoral	June 7- August 27
Dr. Victor A. Greulach Department of Botany University of North Carolina Chapel Hill, NC 27514	Algology, Biochemistry, Ecology, Genetics, Mycology, Physiology and Taxonomy	Predoctoral, Postdoctoral	June 14- August 21
Dr. Glenn W. Todd Department of Botany and Plant Pathology Oklahoma State University Stillwater, OK 74074	Plant Physiology, Ecology, Pathology, and Anatomy	Predoctoral, Postdoctoral	June 7- August 13
Dr. Loren G. Hill Department of Zoology University of Oklahoma Norman, OK 73069	Morphology, Physiology, Ecology, Behavior, Taxonomy, and Genetics of Plants and Animals	Postdoctoral	June 5- July 31
Dr. R. W. Newburgh Department of Biochemistry and Biophysics Oregon State University Corvallis, OR 97331	Biochemistry and Biophysics	Postdoctoral	June 21- August 27
Dr. W. P. Stephen Department of Entomology Oregon State University Corvallis, OR 97331	Insect Behavior, Biochemical Systematics, and Insect Toxicology	Predoctoral, Postdoctoral	June 14- August 27

Dr. Edwin A. Mirand Department of Experimental Biology Roswell Park Memorial Institute 666 Elm Street Buffalo, NY 14203	Biology, Biochemistry, and Biophysics	Predoctoral, Postdoctoral	May 31-August 27
Dr. Raymond W. Holton Department of Botany University of Tennessee Knoxville, TN 37916	Taxonomy, Ecology, Morphology, Genetics, Physiology, and Biochemistry of Cryptogamic Plants	Predoctoral, Postdoctoral	June 14-August 21
Dr. Harold C. Bold Department of Botany University of Texas Austin, TX 78712	Biochemistry, Phytochemistry, Plant Morphology and Physiology, Phycology, Ecology, Systematics, Ultrastructure, and Evolutionary Biology	Predoctoral, Postdoctoral	June 4-August 14
Dr. Jack D. Ives Institute of Arctic and Alpine Research University of Colorado Boulder, CO 80302	Geomorphology, Glaciology, Climatology, Plant and Animal Ecology, and Hydrology	Predoctoral, Postdoctoral	June 14-August 20
Dr. Harry Zeitlin Department of Chemistry University of Hawaii Honolulu, Hawaii 96822	Environmental Pollution in Hawaii	Predoctoral, Postdoctoral	June 21-August 27
Dr. Edwin S. Iversen Rosenstiel School of Marine and Atmospheric Sciences University of Miami and Dr. Albert C. Jones Tropical Atlantic Biological Laboratory University of Miami Miami, FL 33149	Physical Oceanography, Ocean Engineering, Primary and Secondary Productivity, Larval Fish Taxonomy and Biology, Systematics of Fishes, and Parasitology of Fishes	Predoctoral, Postdoctoral	June 8-September 1
Dr. Donald B. Aulenbach Department of Environmental Engineering Rensselaer Polytechnic Institute Troy, NY 12181	Environmental Engineering and Limnology	Predoctoral, Postdoctoral	July 5-August 27

PUBLICATION ANNOUNCEMENT

The following new CUEBS publications will be available in late March. Copies are free upon request.

Publication 30. **Role Playing and Teacher Education,** by David L. Lehman.

This publication expands on the treatment in Publication 25 (Preservice Preparation of Secondary School Biology Teachers) of the technique of situations in science teaching.

Publication 31. **The Use of Modules in College Biology Teaching,** edited by Joan L. Creager and Darrel L. Murray. See article by Joan Creager on p. 14.

Viewpoints!

Biologists and the Environmental Credibility Gap

Lary V. Davis
CUEBS Staff Biologist

As parents, most of us are aware that our children learn considerably more about our beliefs from our actions than they do from our words. There is, I believe, general agreement that the "Don't do as I do, do as I say" approach to child-rearing leaves much to be desired. This approach might be cited as one of the oldest and best-known examples of a credibility gap.

And yet, this is exactly the approach that seems to be guiding most our efforts to educate the public to the environmental issues that face the world today. The curricula of our schools, from elementary schools through universities, are being expanded to include such courses as "Man and His Environment," "Biology and the Future of Man," etc., (see CUEBS NEWS, Vol. VI, No. 3). An important question to be asked about these courses is, "How effective are they in convincing people of the reality of the environmental problems?" If the results of the educational efforts to date are of any predictive value, I contend that future prospects are bleak. For if one examines the number of significant changes that have been made in our approach to the environment, the obvious conclusion is that very few people have been convinced that problems really do exist, or what may be even worse, they are convinced that our problems can be alleviated by picking up all of the tin cans, bottles, and other trash lining our roadsides. Consider, for example, how many of our leaders of industry, government, the scientific community, etc. (ignoring the rhetoric emanating from many of these leaders) have expressed their concern through the initiation of real actions designed to provide real relief for some of our real problems. The failure of our educational efforts is due, I believe, to some glaring discrepancies between what we as biologists say, and what we do.

As biologists and educators, we are placed in a position where it becomes our duty to reach as large an audience as possible, in as convincing a manner as possible. I doubt if the social climate has ever been as favorable for, or as demanding of, biology and biologists. If we do not respond—if we do not meet our responsibilities in such a way that real change occurs in a real world—then we will bear a large measure of the blame for whatever dismal prospects the future may hold for our species.

This means that we must convince people that the environmental issues are real and serious. To do so we must be able to demonstrate that we, as biologists, are ourselves convinced of the reality and seriousness of the problems. If we hope to be convincing, we must do more than introduce a new course into an already bewildering array of courses—more even than introducing whole new curricula related to the environment. We must change not only our lectures but also our life styles, and in such a way that our conviction is evident.

Let me be more explicit. There is little point in arriving on campus (usually, alone) in a 1969 "Imagemobile" (although given the attitudes of most of us, this is more likely to be a badly-tuned 1949 version of the same thing) to deliver a lecture on the evils of air pollution. Nor is there much reason for denouncing power companies for their part in polluting our air and water (even when this is accompanied by scads of data showing how various exotic species of living organisms are being affected by the pollution) while maintaining a household in which virtually every appliance, from garage doors to toothbrushes, is operated with an electric motor. Similarly, there is little use in deploring the anti-environmental decisions of governmental policy-makers, no matter how eloquently we may deplore them, while refusing to leave the sanctity of the research laboratory or classroom to participate in civic activities.

In short, if we want people to believe our words, then the message conveyed by our actions must be consistent with that conveyed by these words of a former president of Case-Western Reserve University, Robert W. Morse:

> Let us not be lulled to sleep by our own eloquence. This nation is now strangling in a curious hypocrisy whereby promise is claimed as performance, whereby wish is said to be fulfillment, whereby slogans and cliches and epithets are substituted for genuine involvement. The nation needs handles, solutions and, most of all, deeds.

AVAILABLE CUEBS PUBLICATIONS

Free upon request from CUEBS, 3900 Wisconsin Ave., N.W., Washington, D. C. 20016

PUBLICATIONS

7. * The consultant bureau. Revised, August, 1967 (for those interested in obtaining curriculum consultant service).
16. * Guidelines for planning biological facilities. August, 1966 (materials including description of facilities consultant service).
19. Biology for the non-major. October, 1967.
20. * Testing and evaluation in the biological sciences. November, 1967.
22. Basic library list for the biological sciences. March, 1969.
23. Teaching and research. May, 1969.
24. Preservice preparation of college biology teachers: a search for a better way. November, 1970.
25. The pre-service preparation of secondary school biology teachers. June, 1969.
26. Biology in the two-year college. April, 1969.
27. Biological prerequisites for education in the health sciences. June, 1969.
28. Investigative laboratory programs in biology. December, 1969.
29. Funds for undergraduate biology departments . . . and how to find them. May, 1970.

* Request by individual letter, to AIBS Office of Biological Education, 3900 Wisconsin Avenue, N.W., Washington, D.C. 20016.

WORKING PAPERS

1. A symposium on investigative laboratory programs in biology. December 1969.
2. A working conference on source material in physics-biology-agriculture and natural resources. June 1970 .

REPRINTS

Council on Education in Geological Sciences. 1970. Audio-tutorial instruction: a strategy for teaching introductory college geology.

Commission on College Physics 1967. Production and use of single concept films in physics teaching.

Creager, J. G. and E. B. Ehrle. 1971. Attributes of biologists in two-year colleges. *BioScience* **21:** 124, 129-135.

Dean, Donald S. 1970. Effective science teaching in colleges. *American Biology Teacher* **32:** 523-526.

Flint, F. F. 1970. Esprit de Core Curriculum. *American Biology Teacher* **32:** 284-286.

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