An Experiment in Undergraduate Teaching and Research in the Biological Sciences

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The papers which form the bulk of this supplement to The Veliger are the outcome of an experiment in undergraduate teaching, conducted at the Hopkins Marine Station during the spring of 1963. The class, a group of 25 Stanford University biology majors, spent the entire ten-week quarter at the Marine Station, enrolled in a new 15 unit course called "Problems in Marine Biology," which met all day, five days a week.

The course was planned and conducted by a three-man faculty which included an invertebrate zoologist (Abbott), a general and plant physiologist (Blinks), and an immunologist-biochemist (Phillips), aided by a teaching assistant with experience in invertebrate development (M. Hadfield). Our general objective was to give a limited group of undergraduates an opportunity to make concentrated studies and to engage in research on individual problems in the area of marine biology.

Fairly early in the planning stages it became clear that the faculty members were in essential agreement on certain features of the approach to be used:

(1) We would plan to start with a broad but brief survey of the marine intertidal zone. Thereafter we would concentrate our attention on a single species, which would be studied in detail in both cooperative and individual research projects. By investigating many different aspects of a single species we hoped to get broad views and insights as well as understanding in depth.

(2) We would make our initial approach as naturalists, looking first at nature in the field. As questions and problems arose we would try to combine the approach of the field observer with that of the experimentalist and laboratory biologist, making an effort to avoid any dichotomy between observation and experiment, or laboratory and field.

(3) We would try to be holistic in our approach, ignoring the fact that biology has been sliced up, for practical convenience, into a number of fields and levels of organization, and considering only that the biologist sees in nature a nearly endless supply of questions and problems, and that he has at his disposal a wide variety of concepts, methods, and tools which he may use in trying to answer or solve them.

(4) Finally, we hoped to plan and conduct the work in such a way that over the ten-week period the students would experience, on miniature scale, not only the activities but also the inner feelings of a scientist engaged in research: the stimulus that comes from realizing how little man really knows and understands, the struggle to formulate a clear problem and a line of attack, the excitement and joy of inquiry and discovery, the intense intellectual and emotional commitment of the scientist to his research, the difficulties and frustrations that may accompany the work, the pleasure of sharing results with colleagues working along similar lines, the struggle to express the results clearly and concisely on paper, and the profound satisfactions that come from even a modest creative achievement in science.

Our attempts to apply this approach and achieve these ends are chronicled below.

Out of 30 applicants for the course we chose 25, fifteen men and ten women. All had had the minimum prerequisite courses (a year of chemistry, and either introductory botany and zoology or a year of biology), and in addition the majority had studied organic chemistry, comparative anatomy, vertebrate embryology, and one or more advanced courses in the biological sciences. As finally selected, the class consisted of 2 sophomores, 14 juniors, 7 seniors, and 2 beginning graduate students. Their previous grade point averages ran from B plus to C.

Before the first day of work the faculty tabulated the student's past records, then split the class up into six teams, each with four or five students. An attempt was made to divide up the sexes, the talents, and the course-work backgrounds represented in the class into six fairly evenly matched working groups. Following this, the faculty went out to the Marine Station's shoreline and selected six different field stations or study areas, one for each of the student teams.

We started work during a week of good tides, with low water occurring in the late morning and early afternoon. On the first class day, after registration and orientation, the class was given an introductory lecture on marine plants. Each team was then provided with graph paper and some elementary surveying equipment (stout cord, a line level, a yardstick, and marking materials) and sent to one of the selected field stations with this assignment: survey a profile strip perpendicular to the shoreline in your study area, extending from the highest splash zone out as far as you can get with safety; along this profile, plot the distribution of the common species of intertidal plants present. The teams were told not to attempt to key out species in the field, but instead to collect all of the different kinds of plants present (insofar as these could be recognized by students in the field), to label each type with a number or letter, and to record their occurrence on the profile charts. The teams went to work without further specific instructions, but faculty members observed the field work, made suggestions where these seemed needed, and called attention to things which might be overlooked. In the afternoon, after the rising tide enforced retreat, the teams returned to the laboratory, identified their collections with faculty help, tabulated and compared results, and in class discussion tried to relate differences in the occurrence and abundance of species with differences in habitat.

The second day, after a lecture on common macroscopic intertidal invertebrates, each team worked its profile a second time, this time recording the occurrence and distribution of common benthic animals. The third day the profile exercise was repeated, the concern this time being the commoner microorganisms, both those in the water and those forming films on the surfaces of rock and weed.

This three day survey, though brief and superficial, allowed each student to become intimately familiar with the topography of one small area and allowed him to sample the more abundant species in each of the kingdoms of organisms present. During the survey everyone became familiar with the most conspicuous of the larger intertidal gastropods, the black turban snail *Tegula funebralis* (A. Adams, 1854), though the students were still unaware that we had selected this creature to be the hero of the course.

On the fourth day the students were given a lecture on the concepts of organism and environment, and were sent out on the ebbing tide with a different type of assignment. Each team was told to "describe the population of *Tegula funebralis* in your profile area." No instructions as to what this involved or how one might go about doing it, were given. We stated only that there was no single "correct" approach or method of procedure; that each team should discuss the assignment, decide for itself what was essential to a "description of a population," formulate its own methods, and get busy for the rest of the day. The students were also told that after lunch on the following day, each team would be assigned a panel of the blackboard on which to plot what they considered to be the essence of their findings, and that each team should elect one member to report to the class on (1) *what* their team had done, (2) *why* they had done what they did, and (3) what they thought they had found out. The teams went to work. The instructors observed, but tried to avoid making suggestions on what to do and how to do it.

Morning on the fifth day passed with a lecture on the sea as an environment, and in student preparation for afternoon reports. These reports, each delivered for the whole class, were most interesting. No two teams had handled the assignment in quite the same way. For example, one team laid out a line of quadrats, counted and measured all *Tegula* present, then plotted numbers and mean sizes against intertidal elevation and distance from shore. Another team with a different orientation recorded *Tegula* distribution in a semi-quantitative manner along a broad strip, noted that the species population was grouped in discontinuous clusters, set up hypotheses which might account for this curious pattern of distribution, and spent the remaining time in designing and carrying out observations and simple experiments to test these hypotheses.

The student reports brought out numerous provocative observations, and raised many questions which the faculty either could not answer, could answer only in general terms, or could answer only in terms of predictions based on knowledge of other snail species. It became clear that to most of us, *Tegula funebralis* was little more than a black shell; that we knew almost nothing in detail of its food, habits, responses, tolerance limits, enemies, growth rate, life span, reproduction, and a host of other matters. We began to tabulate categories of things we did not know about *Tegula,* and out of this came the program for the work of the next six class days.

During this period the tides were poor for field work, and the days were devoted primarily to intensive indoor studies of *Tegula*. Lectures were used to lay a foundation of concept and background information for the practical methods and exercises carried out in the laboratory on the same day. Faculty members alternated in charge of the work, but each attended his colleagues' lectures and observed their laboratory exercises, and each made a real effort to relate his topic of the day to material covered earlier. A brief outline of the program of this part of the course follows (Table 1).

It seems worthwhile here to underline a particularly significant difference in emphasis, separating the present course from the more conventional college biology courses oriented around "principles" of a selected "field," or around particular biological taxa. The organization and stress in these courses generally reflect the viewpoint of the scientist in his capacity as a *teacher*; his stress tends to be on imparting organized knowledge. In principles courses, a firm grasp of the principles is regarded as the important thing; specific examples are regarded as illustrative rather than of great importance for themselves. In courses dealing with specific taxa, imparting a knowledge of the group is the main desideratum. In both types the scientist, as a teacher, is trying to pass on that material within the scope of the course which is of _general_ rather than merely specific significance; he is dealing in statements describing that part of the behavior of the cosmos or of its parts which seems orderly and consistent. In the principles course, organization is around the principles, concepts, or laws. In the taxon-oriented course, while generalizations are sought, principles may or may not receive emphasis; nevertheless they are always assumed to form a constant part of the background. In courses of both types, the orientation and emphasis is usually that of the scientist-*teacher,* striving to impart organized knowledge and clearer understanding.

Our own treatment of principles and other subject matter in the present course differs from the above. And the difference in treatment reflects the difference in attitude between the scientist in his role as a teacher and the scientist in his role as a *researcher*. The dedicated researcher is not so concerned with the broad and balanced view, and with orderly generalization in matters peripheral to his research; for him the most important thing is the problem under investigation. In the researcher's mind and in his hands, principles, concepts, instruments, techniques, and all the rest of accumulated human knowledge and know-how, become mere tools to be brought to bear on the task of answering his question. All human experience and capability become means, to be applied in achieving his specific ends. The tools, in such a view, have no real value in themselves; those which are immediately useful are used, the others are laid aside.

And so it was in the present course. Our aim was *not* to pass on to the students a better grasp of biological principles as such, or a greater knowledge of marine snails

Table 1

Lecture	Laboratory
Basic molluscan morphology, torsion and its consequences, the early evolution of the gastropods, and the anatomy of the Trochacea.	Dissection of *Tegula,* to work out the gross anatomy.
Physical and chemical factors in the marine environment, tolerance limits of organisms, and the concept of limiting factors.	Observations of responses of *Tegula* to various physical stimuli; determination of tolerance limits for several physical factors.
Energy sources and nutritional types of organisms; biogeochemical cycles; enzyme action in proteases and carbohydrases; methods of determining enzyme action; digestion in *Tegula*.	Determination of food of *Tegula* from gut contents; assays to determine the categories of enzymes present in different segments of the gut in *Tegula*.
Obtaining energy; transport of O_2 and CO_2; the excretion of nitrogenous wastes.	Determination of myoglobin and lactic acid in muscles; determination of hemocyanin; determination of nitrogenous waste products in excretory organs.
Receptors, nervous system, and effectors of *Tegula;* responses of *Tegula* and other snails to predators; responses of commensal species to the *Tegula* host.	Observing and measuring responses of *Tegula* to starfishes and predatory gastropods; measuring reponses of *Crepidula adunca* and *Acmaea asmi* to *Tegula funebralis*.
Photosynthesis in marine algae; concepts of standing crop and productivity; intertidal and oceanic productivity; methods of measuring productivity.	Survey of food plant supply for *Tegula* in the field; field determinations of photosynthetic rate using Winkler methods.

as a group, or an increased facility in the use of scientific apparatus, or even a better understanding of *Tegula funebralis*. Our aim was to involve all of the students, intellectually and emotionally, in an intensive and comprehensive *investigation* of a common local species. We chose *T. funebralis* to work with, but it could well have been another species of animal or plant. We looked at the animal and we asked questions. Then we selected those principles, concepts, methods, and instruments *which were needed now in pursuing the answers* to those questions; we introduced them, not as things of intrinsic interest or value, but *as tools for effective inquiry*. At this stage of the work, familiarity with the tool was all we expected; mastery could come later where, in particular cases, a given tool proved crucially important. But our attitude was this: the proper understanding and expert use of tools is not the prime objective of the researcher but only a necessary incidental to his work.

Discoveries new to both students and faculty were made each day. Moreover, the class was beginning to use its time and its tools more effectively in investigation. By the time the tides had again become favorable for field work, it is safe to say that the least informed student in the class knew more about *Tegula funebralis* than had the best informed malacologist in the world only a few days before. Starting with a poorly studied species this result could hardly have been otherwise; nevertheless, the knowledge that they were breaking new ground provided a continuing source of stimulation to the class.

With the return of good tides, the students were given their next big field assignment. We posed these general questions: How does a typical *Tegula funebralis* spend its time? What is the general activity pattern of the *T. funebralis* population, (1) during a 24 hour cycle of day and night, and (2) over a nearly 25 hour cycle of tides?

To facilitate round-the-clock observations, the six original teams were combined to form three teams, each with eight or nine members, and only three of the original profile areas were selected for the proposed study. Each team was instructed to set up its own work shifts, and to plan its approach, methods, and program without faculty aid. Three days were allowed for the exercise.

The first day saw a flurry of activity which ranged from the testing of fluorescent paints and other materials calculated to facilitate night observation, to the laying up of food supplies for the night shifts. Excitement in the exercise ran high and continued high, despite rains, rough water, long hours, and the frustrating difficulties of trying to follow and record the activities of a partially submerged population of purplish black animals at night. This was at least partly because information new to both students and faculty was continually coming in. Up to this time, practically all of our field work had been carried out during daytime periods of low tide, when the *Tegula* population is usually highly clustered and quite inactive. In the present exercise it quickly became apparent that the population was far more mobile and dynamic than suspected; animals dispersed, became clustered again, moved up and down, and otherwise shifted about in pronounced fashion along with changes in light, tidal level, and local current.

Much overtime went into completing this exercise, and when it was over we found the team oral reports absorbing, as much for the student attitude reflected as for the findings on *Tegula*. As one faculty member remarked to a colleague after the reports, "Excellent! Who would have thought you could get a group of 25 Stanford undergraduates so stirred up over the doings of a little black snail?" Reports were followed by a reassessment of the things we had found out about *Tegula,* and further, a listing of some of the questions, problems, and good leads that remained. The list was a long one.

Students were given the weekend and the first part of the following week to survey the list, do a bit of reading and perhaps a bit of pilot investigating, and to select for themselves individual problems which would occupy them for most of the remainder of the quarter. They were lectured on biological literature sources and the use of a research library, and instructed how to use the abstracting and indexing serials, such as Biological Abstracts, Chemical Abstracts, and the Zoological Record. Toward the end of the fourth week, each member of the class handed in a written prospectus for a research problem. This was gone over very carefully with a faculty member, revised, resubmitted, and often rewritten again. A real effort was made to get students to frame their problems in fairly concrete terms, to formulate them in terms of specific and answerable questions, and to limit them to such a degree that there was a reasonable hope that some answers could be obtained before the end of the quarter.

The fifth week of the class began with a talk from each student, covering what his problem was, and how he was planning to tackle it, or at least start on it. Some idea of the scope of the projects attempted may be gained from the following list of abbreviated project titles.

Distribution and movements of the *Tegula funebralis* population.
Factors governing the upper and lower limits of distribution of the *Tegula funebralis* population.
The activity pattern in *Tegula funebralis.*
Orientation and dispersion of *Tegula funebralis* with respect to current.
Responses of *Tegula funebralis* to starfish and gastropod predators.

Interactions between populations of *Tegula funebralis* and hermit crabs.
Photoreception and responses to light in *Tegula funebralis.*
Chemoreception in *Tegula funebralis.*
The anatomy of *Tegula funebralis.*
Structure, growth, breakdown, and repair of the shell in *Tegula funebralis.*
Algae on the shell of *Tegula funebralis,* in relation to the distribution, food, and feeding of the commensal limpet *Acmaea asmi.*
Attraction of the larvae of *Acmaea asmi* to *Tegula funebralis.*
Dispersal of the young of the commensal gastropod *Crepidula adunca* to new *Tegula funebralis* hosts.
Reproduction and larval development in *Tegula funebralis.*
Food preferences and feeding in *Tegula funebralis.*
The carbohydrases in the gut of *Tegula funebralis.*
The proteinases and lipases in the gut of *Tegula funebralis.*
Yeasts living in the gut of *Tegula funebralis.*
Diurnal fluctuations in the O_2 consumption of *Tegula funebralis.*
Production and fate of lactic acid in the muscles of *Tegula funebralis.*
Hemocyanin of *Tegula funebralis.*
Excretory products of *Tegula funebralis.*

In a few cases the projects above were handled by two students working in close collaboration, but the majority were carried out by individuals. Each student was assigned a faculty advisor who aided in finding references and equipment and in getting the project started. For a time there were real problems of space and equipment. Also, it very quickly became clear that no real class work schedule was possible, and that the laboratory would have to be open and available 24 hours a day, seven days a week. No formal lectures or labs were therefore held. Students were expected to report to their advisors periodically, but student independence and initiative were encouraged as much as possible. There was surprisingly little "goofing off."

By the middle of the seventh week, work had progressed to a point where the findings of one student were beginning to throw light on projects tackled by others. We therefore scheduled a series of small conferences, each attended by a few students working on interrelated problems and by one or two faculty advisors. Topics around which discussions were organized included the following:
Distribution of *Tegula funebralis* and ecologically related species, and factors affecting that distribution.
Sensory reception.
Commensals and predators of *Tegula funebralis.*
Food habits and feeding.
Digestion.
General physiology.
Structure, development and growth.

In most cases, an individual student was assigned to two different groups, so his findings could be considered from at least two different points of view. Students were asked to bring in their data in organized form, and to be prepared to present and discuss them with others.

We hoped the interchange in these discussion groups would in some ways compare with that experienced at small scientific meetings limited to investigators working on closely related problems. The results in most cases did not live up to our expectations, and in retrospect it is clear that those expectations were too high. A number of students were still struggling with methods, and discussions in some areas centered on these. Some students brought in quantities of undigested data. Only a minority presented findings effectively in the form of tables or graphs. Among the lessons learned was this: that unless problems and findings were presented in clear, concise, organized form, and illustrated graphically in some manner, the investigator failed to get much across to his audience, and discussions lagged or never got started, or were restricted to comments by the faculty advisors. Nevertheless, it appeared at this stage of the work that the findings of a majority of students included some small but original contributions to science, of particular interest to malacologists.

With this in mind, the faculty contacted Dr. Rudolf Stohler, editor of The Veliger, presented a brief outline of what the student group was doing, and inquired whether or not papers resulting from the course might be considered for publication in that journal. Dr. Stohler's response was immediate; the course sounded interesting, and any papers resulting from it would be considered for publication providing they passed editorial board inspection. There was no guarantee that all or any papers would be accepted, but if a sufficient number proved suitable, it might be possible to issue a sort of "Symposium on *Tegula*" as a supplement to The Veliger. Word of this response was passed to the students, and this provided an additional stimulus.

The eighth and ninth weeks of the course passed in research and in conferences between students and their advisors, and the lights in the laboratory burned very late. A deadline for turning in final drafts of papers to faculty advisors was set at the end of the ninth week, a full seven days before the end of the course, in order to allow time for rewriting. In a lecture on the subject of writing and illustrating scientific papers, it was stressed that not only must a scientific paper have something to say, but it must say it in an organized fashion, concisely, and with unequivocal clarity; students were referred to current biological periodicals for specific examples.

Oral reports on research projects occupied three successive mornings of the final week of class. These talks were attended not only by all members of the class and faculty, but also by other graduate students and investigators in residence at the Marine Station at the time. An effort was made to hold the talks under circumstances approximating those of a regular small scientific meeting. Individual reports were limited to one-half hour each, and were accompanied by illustrations and graphs from student papers, projected by means of an opaque projector. The reports went very well. For the most part they were organized and had been rehearsed, and were delivered in a manner comparing favorably with that of professional scientists at meetings. We were exceedingly proud of student performance here.

All of the remaining time during the last week went into criticism and revision of the written research reports. Despite instructions, most of the written reports resembled first drafts of undergraduate term papers rather than scientific manuscripts. The best were none too good, while the worst were longwinded, chatty, poorly organized, and frequently incoherent. The papers were gone over in student-advisor conferences, criticised in real detail, sentence by sentence, torn apart and reorganized, and sent back for rewriting. The rewritten version was also criticised, and often sent back for further revision. Those papers which passed the review of the faculty, and that of the editorial board of The Veliger, are presented in the following pages.

On Growth and Longevity in *Tegula funebralis*

(Mollusca : Gastropoda)

BY

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(Plate 1)

Alex Comfort (1957) has reviewed the literature on the life-spans of mollusks, and has gathered together the published longevity records for members of the phylum. Reference to his listing reveals that the more long-lived forms fall into two categories: (1) Bivalves, in which age can be estimated with fair confidence from annual growth rings on the shell, and (2) the more primitive marine gastropods, in which age determination by annuli has been generally unconvincing and is instead usually inferential from growth rate data and/or size-class groupings. It is the purpose of the present paper to offer evidence which suggests rather forcefully that the black turban snail, *Tegula funebralis,* has a life-span greater than that recorded for any other gastropod, and that, unlike other members of the group, the ages of individuals of this species (at least in the population studied) may be approximately determined by counting growth lines.

During the 9-month period from October through June, 1959-60, a population of *Tegula funebralis* was studied at Sunset Bay, Coos County, Oregon, in an attempt to determine the annual pattern of growth and mortality. The problem was suggested by Dr. Peter W. Frank of the University of Oregon, and the work was carried out under his guidance and with funds from the undergraduate research participation program of the National Science Foundation.

Unfortunately, the establishment of a long-range study program utilizing large sample sizes was frustrated through lack of a successful technique for marking and recapture. Two sorts of tagging methods were attempted on the 880 animals eventually released. Initially, numbered monel alloy tags (fig. 2) were attached near the lip of the shell by drilling small holes with a high-speed electric tool and dental bit. Subsequent observations on the 600 animals