AN INTERDISCIPLINARY APPROACH TO TEACHING PHYSICS: BIOLOGY IN RELATION TO PHYSICS

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ABSTRACT

The primary concern of this study was that neither the regular physics nor the PSSC physics curriculum had any apparent relevance to students interested in pursuing careers in biological/medical sciences. These students were studying physics either in an adult education center or in a private secondary school. To tailor the curriculum to the needs of these students, the physics course was enriched as often as possible, in as many ways as possible, with examples of the relationship between physics and the biological/medical sciences. Enrichment material was presented in the following areas: lectures, reading, problems, demonstrations, laboratory work, term papers, projects, bulletin board displays, and career information. The success of this innovation can be inferred from the positive classroom atmosphere created and from the students' enthusiasm for this interdisciplinary approach.

ABSTRAIT

L'intérêt principal presenté par cette étude était que les programmes d'études de physique régulier et de physique PSSC n'avaient pas de pertinence pour les étudiants qui espéraient poursuivre des carrières dans les sciences de la santé. Ces étudiants suivaient les cours soit dans un centre d'education des adultes soit dans une école secondaire privée. Afin de mieux répondre aux besoins des étudiants, le professeur faisait les liens entre la physique et les sciences de santé le plus souvent possible. Le materiel d'enrichissement presenté aux éléves incluait des presentations, la lecture, des problèmes, des travaux de laboratoires, des expériences, des projets et les renseignements sur diverses carrières. L'enthousiasme exprimé par les éléves devant cette approche interdisciplinaire démontre le succès de cette innovation.

> A joyful life is one of constant meaningful intercourse with others in a meaningful environment , equal enjoyment does translate into equal education (Illich, 1971: 60).

Section I: STATEMENT OF BASIC ENDS OR PRINCIPLES OF ETHICS OR SOCIAL THOUGHT.

The person new to the teaching profession can walk into the classroom fully prepared from the academic point of view, but totally unprepared from the philosophic point of view. The emphasis in the teacher-training programs tends to be on the concrete material and the logistics to be dealt with in the classroom rather than on the broader global objectives of the educational system. Often only one course in educational philosophy is required which surveys the main lines of thought in the twentieth century while barely alluding to the philosophic base upon which the Western educational system is built.

Initially, this does not create a problem since the first few years of teaching are filled with demands on the concrete level, i.e., learning the course material, learning about the school, learning about the students, and learning about the peer group within which she must function. However, once these demands have been met, and the teacher begins to feel comfortable in her role, a need arises to identify her assets and liabilities, and to identify and justify her prejudices and assumptions. The result of this self-appraisal should be the establishment of a classroom environment which is uniquely her own, which is a joy to her and to her students and one which fulfils the demands of the society in which this whole interaction is taking place.

The demands of the society are often stated as part of the objectives of the education department of the controlling political unit. In Québec, the Ministry of Education has published its objectives as part of its policy statement on the schools of Québec.

The two global objectives of the Secondary Level are:

> 2.3.8 The secondary school is concerned for the most part with preparation for professional and social life.
>
> 2.3.9 As adolescents grow up, usually between the ages of 12 and 18 years, they become increasingly aware of the responsibilities which will become theirs when they have to decide their future. The objectives of education in the secondary school take this fundamental characteristic of adolescence into account (Gouvernement du Québec, 1979:30).

Thus, society expects the classroom environment to reflect not only the job-oriented needs of the individual, but also the needs associated with developing into a socially responsible citizen. The key words here for the classroom teacher are "preparation" and "future": the ultimate thrust of the classroom is not "here and now" as it so obviously seems to be, but "there and then."

What type of data does the teacher have to guide her in fulfilling these goals? In terms of the students' future professional life: What types of jobs will be available? What types of skills will be in demand? What aspects of the job will the student most value - money, prestige, excitement, access to leisure or intellectual stimulation? My response is that none of these questions can be answered: the only certainty is uncertainty. But perhaps a more positive approach would be to say that the only certainty is change, and that the classroom environment must be such as to enhance the students' ability to deal with that change. Our society needs the "kind of individual who can live in a delicate, but ever-changing balance between what is presently known and the flowing, moving, altering problems and facts of the future (Rogers, 1981:41)."

In terms of trying to develop a socially responsible citizen, the same types of questions arise. In what type of world will the individual be living forty years hence? What type of decisions will the citizens of Québec be expected to make? How will advancing technology affect the citizens' control (or lack thereof) of their lives? What will the gap between the public understanding of science and technology and the requirements of citizenship in a participatory democracy be like? Again, the unknown outweighs the known. The major skills that need to be provided are those that aid the individual in dealing with new situations. It is not the known facts that will be important in the future, but the ability to deal effectively with those facts. It is not the status of reality that will be important but the nature of the reality. For Peters, it is an approach to thinking that will enable the future citizen to deal with the future reality:

> One attempts to get others on the inside of a public form of thinking in which assumptions are challenged and techniques mastered for deciding who is right. Specific types of concepts and truth criteria have to be understood. Above all the passion for truth must be conveyed that gives point to the search for evidence, the abhorrence of irrelevance, incoherence, and arbitrariness, and the love of clarity and precision (1970:113).

In addition to the global objectives stated above, the Québec Ministry of Education also provided specific objectives for the second cycle, secondary level:

- to consolidate and pursue in greater depth, by means of more systematic learning, the fields of knowledge and technology;

- to provoke personal commitments which emphasize the feeling of belonging and encourage participation and creativity;

- to work at increasing in young people the sense of individual and collective responsibility;

- to promote in students the structuring of coherent thought, through both optional and compulsory subjects;

- to develop in students a critical attitude in the face of various intellectual trends by which they are solicited;

- to help young people find a meaning in life;

- to facilitate access to future professional life (Gouvernement du Québec, 1979:31).

Although these specific objectives in small part reassert the contents of the global objectives in terms of the future, they are, to a larger extent, stated in terms of the here and now. These specific objectives should enable the teacher to produce a list of tasks for the student to accomplish. First, the student should be encouraged to master the core curriculum - the basic knowledge and skills associated with any one topic in the syllabus. Secondly, activities which foster creativity, initiative, class participation, and critical thinking should also be made an integral part of the classroom procedure.

Section II: EMPIRICAL OR OTHER PREMISES ABOUT HUMAN NATURE, LIFE OR THE WORLD.

Having identified to some extent the basic objectives of the educational process, it is necessary to examine the components of that process to determine the premises upon which the attempts to achieve these objectives will be based. In the traditional educational situation, four components have been recognized: the "hidden curriculum," the problem, the learner, and the teacher.

The Hidden Curriculum

The hidden curriculum is defined by Illich as a course of instruction in which the

> . . . students learn that education is valuable when it is acquired in school through a graded process of consumption; that the degree of success the individual will enjoy in society depends on the amount of learning he consumes; and that learning about the world is more valuable than learning from the world (1971: 45).

The identification of this assumption by an establishment educator (i.e., one who believes that schools are basically good) is usually of no great importance when she is working strictly within the system. But should the educator become involved with the slightest aberration of the system, such as adult education classes, then the acknowledgement of the value of education obtained outside of the school system becomes crucial. Many adult students return to school with the knowledge that society accords special privileges and high incomes to the people who have acquired their expertise through the system. They are also aware, however, that there is a lack of correspondence between schooling and occupational competence. Any educator who deals constructively with adult education classes must be prepared to deal with the anger and frustration caused by these contradictions. Acceptance of the student's work and life experiences as valid contributions to the class discussion encourages the adult student's participation and places value on "learning from the world." The facilitation of this participation depends upon certain attitudinal qualities which exist in the personal relationship between the teacher and the student. In Rogers view, the acceptance of the student as an individual, whose life experiences have inherent value, leads to prizing the learner and that, in turn, to a better teaching atmosphere (1967:44).

The Problem

The second component of the traditional educational situation, the problem, involves the material to be taught whether it is knowledge, skills, or attitudes. Bloom's Taxonomy of Educational Objectives separates knowledge into various categories from simplest to most complex:

(1) knowing a definition or a fact;
(2) performing a single operation or using a single formula;
(3) knowing an abstract concept;
(4) performing operations using symbols;
(5) comprehending an abstract concept;
(6) excluding irrelevant data and application of an abstract concept (1956:201-204).

Horn's skills taxonomy yields a similar categorization for the various skills associated with the scientific method. Again, from simplest to most complex, these include:

(1) the ability to gather, organize and evaluate information concerning a problem;
(2) the ability to formulate, explain and discuss hypotheses based on the pupil's own knowledge and perception of a problem;
(3) the ability to plan an experiment;
(4) the ability to set up and conduct an experiment methodically;
(5) the ability to analyze, interpret and describe the results of the experiment;
(6) the ability to formulate clearly the pupil's own conclusions and to interpret and criticize objectively the conclusions of others;
(7) the ability to use and apply the conclusions of an experiment (1968:242-259).

It is valuable for the classroom teacher to know where the problem she is trying to solve with the class fits into the cognitive or the skills hierarchy. Since the new courses developed by the Québec Ministry of Education, specifically the new physics program (Gouvernement du Québec, 1981), are organized by objectives stated in just these terms (e.g., organize, formulate, analyze, describe, and distinguish between) much of the ground work for this task has been already laid. There are also some attitudinal objectives in the new program for physics, as for example, the objective which states, "To NAME at least five ways of saving energy in everyday family life (Gouvernement du Québec, 1981:45)." Implicit here is the attitude that saving energy is a task to be valued in this society.

The Learner

Can the third component of the educational system, the learner, be classified? What basic premises about human nature can be identified which will contribute to the attainment of stated objectives? One obvious classification is that of adolescent or adult. Adolescents, with their wide range of emotional actions and reactions, and their authority-questing and authority-testing behaviour can be demanding in ways adults rarely are. Some class time must be spent dealing with the facts of adolescence rather than with the facts of science. Adults create other types of demands which often hinge on their past experience with authority and/or schooling and on the fact that their opinions are better developed and often rigidified.

It is also important to understand the students' perceptions of themselves and their role in the system. Do students see themselves as freely participating agents of their own educational process or do they feel that they are being coerced into what other people have decided is good for them? The perceived coercion usually takes the form of "recommendations" by guidance counsellors or parents which the student feels unable to ignore, or in the form of prerequisites for community college or university programs. Holt feels that under these conditions the ability of students to deal with the course content is overwhelmed by their inability to deal with the perceived rigidity, irrelevance, unnecessary restrictions and lack of spontaneity of the system (1973:43).

It is essential that the teacher and the student understand why the student is taking the course before a positive learning environment can be created in the classroom.

The learner can also be classified according to her stage of intellectual development. Piaget has developed a scheme of intellectual development which describes various stages in the life of the individual. The child at birth is in the sensory-motor stage during which the child is in the process of acquiring practical knowledge. From roughly eighteen months to seven years, the child is in the preoperational stage, a stage characterized by intellectual rigidity and egocentricism. The concrete operational stage follows directly the preoperational stage. In the concrete operational stage the child can relate to the actuality but not to the abstraction. The term "concrete" is used because the child is involved directly with the object and not with statements or hypotheses about the object. As the child emerges from the concrete operational stage, she enters the formal operational stage. In this last stage the child no longer needs the object in order to think about it. The individual can think beyond the present, can form hypotheses and act on them, and can control and isolate variables(Renner and Lawson, 1973:168). Obviously, the latter is the type of thinking that should be promoted in the high school classroom.

Another very important aspect of Piagetian theory is the sequential nature of the stages. Each stage must be passed through in order. The students cannot assimilate material on the formal operational level for which they have not created mental structures on the concrete operational level. The students must operate at their own level: they cannot do otherwise.

In an attempt to classify Québec students in this schema, P. Désautels tested students entering the Collège de l'Enseignement Général et Professionnel de Rosemont (Rosemont CEGEP) in 1977 (Désautels, 1978: 121, quoted in Gouvernement du Québec, Secondary School Curriculum Physics Block I Block II, 1981: 7). He found that ten per cent of the students entering the Rosemount CEGEP were at the concrete stage, ten per cent were at the formal stage and eighty per cent were in transition. Since most secondary students in Québec take physics the year immediately preceding CEGEP entry, these percentages give a good indication of the intellectual level of the typical secondary school physics student, the clientele discussed in this paper.

It is also important to realize that students are not necessarily at the same intellectual level in all aspects of their learning. For example, a student might be in transition with respect to language concepts but be at the concrete stage with respect to science and mathematical concepts. This must be taken into account when planning a physics program.

The Teacher

The fourth component of the educational system is perhaps the hardest to dissect, discuss and classify: the teacher, herself. It is much easier to objectify the hidden curriculum, the problem and the learner than to objectify oneself, but it is absolutely necessary to try. By establishing procedures for certification, society has in part defined a teacher as "a person whose experience and special training has given him some mastery of one of these modes of experience, i.e., scientific, moral and/or aesthetic (Peters, 1970:113)." This mastery, although a necessary condition, is not a sufficient condition. The ability to relate to other people, variously expressed as empathy, understanding, sensitivity and acceptance are important criteria as well. The teacher should have the ability to share not just objects, but also knowledge, joy, confusion, sorrow, hurt, and pride. She must be able to recognize that it is not "the class and the teacher" that have to solve the problems in the classroom, but that it is "we" that have to do the solving. She must have the flexibility to allow for individuality, yet the firmness to give direction to the classroom experience.

Self-knowledge is perhaps one of the major keys to classroom success. The teacher must know what she values and why she values it; what she is willing to fight for and what she can concede; what her strengths and weaknesses in her field are. This critical self-appraisal gives rise to a methodological consistency in the classroom which is respected by the students.

The teacher must also decide how she is going to deal with the system itself. When dissatisfactions arise - from the students or from within herself - how will she deal with them? The choices are to innovate or to reform. To innovate means to introduce a new idea or method without changing the existing curriculum; to reform means to change the curriculum. Most teachers, in fact, do not have a choice: the system is set and the only change allowed is innovation. However the teacher chooses to deal with the dissatisfactions, she must be able to justify her choice and to implement it with firm conviction..

Could the innovations proposed in this paper (i.e. inserting biological/medical examples into the physics curriculum) be implemented within the framework of the traditional classroom as it has been identified above and still meet the objectives set by the Québec Ministry of Education? Could the introduction of these biological/medical examples into the physics curriculum facilitate the achievement of the curricular and the global objectives? Would these enrichment components be within range of the capacity of the students? Would they relate to the experience the students were having at that time? Would they arouse in the student an active quest for information and for the production of new ideas - all criteria which must be met when selecting material for inclusion in a classroom program (Dewey, 1938: 79).

In an attempt to justify these innovations, let us examine a specific objective from the optics section of the <u>Physics Block I Block II</u> program:

> 2.5.01 To DESCRIBE the principal foci (real focus and virtual focus) of a thin-edged convex lens. (DECRIRE foyers principaux (foyer-objet et foyer-image) d'une lentille mince convergente.) (Gouvernement du Québec, 1981: 49).

This type of curricular objective, once achieved, would help the student to consolidate a field of knowledge, thus fulfilling the first of the specific objectives of the Québec Ministry of Education for secondary students (see p. 10). The cognitive level demanded by this objective would fall into Bloom's simplest category: knowing a definition or a fact (see p. 13). Given that most of the students are concrete operational learners or in transition to the formal level, it is necessary not only to write the definition of the principal foci on the blackboard and to explain it, but also, to provide a thin-edged convex lens and a source of parallel light rays, and to show the class that the lens does indeed converge light rays. It would be even better to have two or three different lenses on hand to demonstrate that lenses as a group have this characteristic not just the one lens tried originally. I also find it useful at this point to ask the students if they can provide the class with a thin lens for demonstration purposes.

After some initial confusion (during which they all deny having anything of the sort), someone will finally realize that I am referring to the eye and a discussion will ensue as to the correctness of comparing the lens of the eye to the lens on the desk. Even the most bored student will usually take part in this discussion since it is, after all, about her! Here we have the fulfillment of the second specific objective of the Québec Ministry of Education for secondary students: to provoke personal commitments which emphasize the feeling of belonging and encourage participation and creativity (see p. 10). Every person has an eye; therefore, every student can join the discussion and have something to say. As a matter of fact, it is often the academically weak physics students (as far as marks are concerned) who make the original connection and who then go on to connect the function of prescription lenses with changing the focal length of the eye, or who ask if the compound eye of the insect is also "a lens." The creativity of the student is given wide latitude in these discussions.

The fact that physics material is so relevant to the biological/medical field is very thought provoking for some students and provides an appreciation of the interdisciplinary approach. The fact that the world is a coherent, cohesive whole is not the philosophy promoted by the traditional compartmentalization of the typical secondary school curriculum. Thus this type of discussion promotes the structuring of coherent thought in the student, another specific objective of the Ministry (see p. 10).

With a little more direction, this discussion can also be used to fulfil the last specific objective of the Ministry - to facilitate access to future professional life (see p. 10). The class can easily be led to a discussion of the various professions which on the surface seem far removed from the physical sciences but which have in reality a demand for solid understanding of physics facts. In addition to the medical personnel, including health technicians who might be involved with the human eye, the discussion could encompass the zoological professions (including veterinary surgeons) which might be dealing with other eyes (vertebrate or invertebrate) or those professions which handle the health and safety regulations relating to the eye. Many career possibilities can be discussed in a short amount of class time.

As a second example, we can consider a task that the students might do in order to be able to better describe the principal foci of a thin-edged lens: given a convex lens, be able to find the focal length using sunlight. The complexity of the task can be ascertained in order to develop an approach appropriate to concrete operational learners. Using Horn's hierarchy of skills difficulties (see p. 14), this task can be seen to be of moderate difficulty (viz., it requires the ability to conduct an experiment methodically). The students cannot just be observers, but must do the experiment themselves. Typically, each student would be provided with a lens and assigned the task with no explanation. There is often initial confusion about how to "use" sunlight, but most of the class will finish in fifteen minutes. They are then asked to find the focal length of the lens of the eye. Here again, the biological example is being used to add to the student interest and to reinforce the physical concept.

We, as a class, after some discussion usually come to the conclusion that it is impossible, using the information that we have, to complete the task as presented. This discussion has then taken a few interesting turns. One class got involved with the idea of approximating the focal length of the eye by looking at the physical features of the human head, and then went on to verify their impressions using measurements provided in the encyclopedia. Another class had an active discussion about the difficulties that a biological scientist encounters when working with organisms that can inflict pain or feel pain in the process of experimentation (specifically discussed were medical ethics, anti-vivisectionism and the morality of pursuing knowledge for the benefit of human kind no matter what the cost to other organisms). Another class decided to experiment on another organism instead of humans and appeared the next day with a fish head from the local fish shop (much to the horror of most of the class). The students dissected out the lens and tried to repeat the experiment. It did not work because the lens was already clouded due to the denaturing of the protein. But this led to a class discussion on the changes that occur in biological molecules upon the death of an organism.

From these two examples, it can be seen that the curricular objectives were met in that the students were presented with the physics material. The introduction of the biological/medical examples helped to consolidate this physics material by providing a second, related but not identical, problem. With the introduction of these examples, other positive factors have been noted: a feeling of belonging and a sense of participation has been created; room for creativity has been provided; relationships to other careers have been explored; the students' sense of collective responsibility has been called upon. if the students wanted to look at the lens of the fish eye, they had to obtain it. It was their idea, and it was their responsibility to carry the project through. But the most important factor is that these activities are successful in that the students find them very interesting. They feel that they have some control over the material and that this open-ended approach responds to their needs and interests. It gives them the motivation to stay with the physics material even though they often find it very difficult.

Section III: OBSERVATIONS ON MY WORLD, THE DISSATISFACTIONS AND HOW I TRIED TO RESOLVE THEM.

Over the years that I have been teaching physics, I have been involved in two types of physics classes: a Physical Sciences Study Committee (PSSC) secondary five class in a private school during the day and a regular stream (secondary five level) class at an adult education center in the evening.

Despite the seeming disparity between the two groups, many similarities were found. The standard student dissatisfactions were always present: "This is boring." "What use is this stuff anyway?" "No one takes my interests into account." "I don't understand." As were the standard teacher dissatisfactions: "There are too many students in the class." "There are too many levels in the class." "There is not enough time to teach all this material." "The students lack the prerequisites for the course." But perhaps the most interesting common denominator was the fact that a large percentage of both groups was interested in the biological/medical sciences. A great number of the students in the day class intended to attend medical/dental school while most of the evening class intended to attend a three-year CEGEP program in nursing or one of the medical technologies.

This can be substantiated by the sampling I took of the evening classes (from Spring 1977 to Fall 1980) and of the day classes (in 1982). The students were asked to specify the CEGEP program to which they would be applying upon graduation from secondary school. The results are presented in Table 1.

TABLE 1

STUDENT INTEREST AS SHOWN BY THEIR CHOICE OF CEGEP PROGRAM

Program Choice	Evening Students		Day Students	
	Number	Percentage	Number	Percentage
<u>Pre-University Programs</u>				
Health Sciences (Pre-medical/Pre-dental).	11	13	15	56
Pure and Applied Sciences.	7	8	1	4
Social Sciences . . .	2	2	2	8
Commerce.	2	2	5	19
Music	0	0	1	4
<u>Career Programs</u>				
Radiography	1	1	0	0
Nursing	47	55	1	4
Community Recreation.	1	1	0	0
Data Processing . . .	1	1	1	4
Dental Hygiene. . . .	3	4	0	0
Nutrition	1	1	1	4
No CEGEP intentions .	9	10	0	0

From this compilation, it can be seen that although the emphasis differs, the basic interest in biological/medical sciences does not. Well over half the evening students enrolled in physics intended to go into nursing, while a similar proportion of day students intended to go into medical or dental programs. Interestingly, if all of the evening students interested in the biological/medical fields are combined, it is seen that seventy-four per cent of the evening class has some type of biological/ medical career in mind. It can be inferred that most students were not in physics owing to an intrinsic interest in the subject, but because physics was a prerequisite to the CEGEP programs that they had chosen. The evening students in particular were very vocal about this fact.

Being aware of the orientation of my classes, I felt that the ideal presentation would be a career or interest-oriented physics course. This tactic had been used successfully to link physics with other career specialties, e.g., journalism (Christensen, 1978), police science and photography (Uhrich et al., 1979) and ecology (Gerson, 1973). Linking physics to the students' own personal needs should strengthen their motivation and improve their retention of principles which they see are closely related to their potential future employment.

The simplest way to start seemed to be to introduce a new textbook. In a survey of the field, I found many texts written with this type of student in mind, e.g., Physics for Biologists (Duncan, 1975), Physics for the Life and Health Sciences (MacDonald and Burns, 1975), General Physics with Bioscience Essays (Marion, 1978) and Physics with Illustrative Examples from Medicine and Biology: Vol. 1 (Benedek and Villars, 1973).

Some of these texts (e.g., Benedek and Villars, 1973) are aimed at the college level student in an introductory course in physics who has a basic understanding of calculus which is too high a mathematical level for secondary school students. Other texts (e.g., MacDonald and Burns, 1975) had a relatively slight emphasis on mathematics, relying on simple algebra and trigonometry. But these texts were again directed at the college level student, and my students who tried sections of this text found the reading level too sophisticated. The other two texts were examples of the type that had short and/or inadequate explanations of the basic principles of physics involved, along with illustrative biological applications of these principles. It seemed that the discussion of the biological material took time away from the basic physics concepts, something that the secondary school student can ill afford. As a well known physics educator commented:

> It is necessary to give students an adequate frame of reference, and that means it is essential to study enough of the relevant substantive scientific subject matter to make such discourse and discussion meaningful (Arons, 1973: 779).

I felt that core material of the physics program should not be sacrificed for enrichment from the biological/ medical field, hence no change in textbook was made.

This meant that the enrichment material had either to be inserted into the regular classroom material or to be assigned to the students as extra work outside of class. At this point, the lack of free time in the students' schedules became the deciding factor. The day school students were in a double curriculum (Hebrew and secular courses) which resulted in a nine period a day schedule (from 9 a.m. to 5 p.m.). The evening students were scheduled for a three-hour physics session once a week, which for most of them, took place after a full day's work. Given this situation, I felt that the enrichment material must be included in the day-to-day class material in small doses and/or be provided as optional material for those highly motivated individuals.

Before looking for material to include in the course, I tried to get some information from the students about their concerns and interests. In the fall of 1978, I gave my fifty physics students (day and evening) a questionnaire which is reproduced below. The number to the left of each item shows the average student response.

STUDENT QUESTIONNAIRE

Please rate the following statements on a scale of -5 to 0 to +5 with -5 being violently disagree, 0 being don't know or neutral and +5 being totally agree.

+1.4 1. I would like to read an article about physics.

+1.7 2. I would like to read an article about chemistry.

+2.6 3. I would like to read an article about biology.

+1.0 4. I would like to read an article about biophysics.

+3.4 5. I would like to know more about the instruments used in the field of medicine.

+1.7 6. I would like to know how people decide whether water should be fluoridated or not.

+2.1 7. I would like to know how an oil spill in the Arctic would alter the eco-system.

+2.6 8. I would like to know the physics principles that explain how eye-glasses work.

-3.0 9. I believe that humans have succeeded in discovering all the physical and chemical principles that underlie human physiology.

+2.0 10. I believe that scientists work hard for their money.

-0.8 11. I believe that physics and biology are mutually exclusive disciplines.

+1.3 12. I believe that a biologist needs to know a lot of physics in order to fully understand her work.

+3.0 13. I believe that a biologist needs to know a lot of chemistry in order to fully understand her work.

+3.0 14. I believe that a chemist needs to know a lot of physics to fully understand her work.

+0.5 15. I believe that ESP will someday be explained in terms of physics principles.

+2.0 16. I believe a statement found in my chemistry text more than one found in the Montreal Star.

+1.8 17. I believe that the study of biology rests on the definitions of key terms.

0.0 18. I believe that chemistry is more satisfying to study than biology because there are more things to explain and fewer to memorize.

<u>+3.7</u> 19. I believe that the importance of models, theories, and concepts lies in their ability to help me relate to and organize new knowledge.

<u>+2.1</u> 20. I believe that it is important for a person to have enough scientific background to be able to understand current theories and concepts as presented in the Montreal Star.

<u>+3.0</u> 21. I believe that I am aware of flaws of logic or procedure in most television commercials.

<u>+0.1</u> 22. I believe that if I knew more about electricity I would understand the human nervous system better.

<u>+2.7</u> 23. I believe that it is best to use many sources when trying to understand a scientific concept.

<u>+2.7</u> 24. I believe that noise pollution has not been fully investigated.

Using the data thus obtained, I hoped to be able to develop a method of incorporating the biological examples which would best suit the students' needs and interests into the physics curriculum. From the results of items 1, 2, 3 and 4, I found that the students were most attracted to reading biological articles as opposed to articles related to the physical sciences. The high scores of items 5, 8 and 9 show a strong interest in medical subjects. A comparison of items 12, 13, 14 and 22 shows that the students see the inter-relationship between the other sciences better than that between physics and biology. This information led to a search for enrichment material identifiable as biological or medical in nature that would stress the need for a basic knowledge of physics.

<u>Adult Education Evening Classes Discussed in Detail</u>

It was the adult education students that first prompted me to look into the interaction between biology and physics. As shown on Table 1, the majority of these students were in physics class because they had to be. They wanted to be accepted in CEGEP career programs which had physics as a prerequisite. Many of them were very vocal about their resentment of this imposition of what they perceived as unnecessary requirements. As far as they were concerned, physics had no relevance to the biological/medical sciences and could only be perceived of as an obstruction on the path to their careers. An obstruction placed there by some incompetent authority figure who had no idea how important time was to them, and who was just trying to fill up a few more classes to provide jobs for teachers.

Added to this general feeling of frustration at "wasting time" were two other factors. In many cases these students felt that they had been sinned against in secondary school either by omission or by commission. Under the category of omission were placed those situations in which the guiding adults had looked the other way when the students had decided against taking a math or a physical science option when earning their secondary school leaving certificate. Under the category of commission were placed those situations in which the guiding adults actively steered students who were interested in "people-oriented" careers towards humanities courses with the result that these students also graduated from secondary school without having taken a math or a physical science option. The comment was made repeatedly that either the physics requirement had never been made known to them or that the need for math and science had been de-emphasized in regard to nursing and other biological/ medical career programs. That there is some substance to the accusations is illustrated by the case of one student who was in her last semester of the career nursing program before the physics requirement caught up with her. She simply had not believed that the prerequisite could affect her until she received a letter stating that she would not be able to graduate from the nursing program until she had passed a secondary level physics course. This phenomenon is not limited to Québec either. In a 1982 report on <u>Education in the Sciences</u>, the American Association for the Advancement of Science stated:

> Students don't see that science is important to them personally, and <u>neither do</u> many of their <u>parents, teachers or school counselors</u> (emphasis is mine) (November 1982:4).

The second frustration factor involves the fact that these students had already been working, in most cases, in their field of interest. Upon re-examining the information collected for Table 1, I found that most of the nursing candidates were already working as nurse's aides; that the person interested in a career in nutrition had a job in a hospital kitchen; and that two out of three of the people interested in the dental hygiene program were working in dentists' offices. This on-the-job experience gave the students the feeling that they already knew what was necessary for their work, and that they already had many of the skills and much of the background knowledge required. One student in particular complained, "I started as a secretary in the dentist's office. When the dental assistant was ill, I was trained on the job to replace her. Now the dentist says that I have to obtain my papers if I'm to continue doing what I'm doing already! Making me take all these courses is a waste of time!" The students perceived the need for legitimizing their credentials as demeaning their work experience.

Along with this resentment of the physics course specifically, these students brought a tremendous load of psychological baggage with them from their previous encounters with the educational system. Fear was a big problem. Fear of failure loomed large on the list as most of these people were in adult education classes because they had been unsuccessful in the regular day school program. Fear of the unknown was also important in that this was the first attempt many had made to integrate into a new type of formal schooling since they had become part of the work force. Fear of physics was part of this fear of the unknown. The only thing that many of them knew about physics was that it was hard! Finally fear of math entered into the picture as many of the people had failed in their previous encounters with math and saw no reason to suspect that they might succeed this time.

It is interesting to note that of the sixty-three evening students interested in the biological/ medical sciences (see p. 27), all but three of them were women. Some of these same fears discussed above have been documented by people interested in preparing women for re-entry into the work force after years as house-wives (Gouvernement du Québec: Conseil du Statut de la Femme, 1981:226-227), by groups interested in preparing women for non-traditional trades (Ibid.:219-221), and by people working on math anxiety (Tobias, 1978:89). Perceiving the problem as a feminist issue added to my motivation to alleviate as many of the problems as possible.

The resulting feelings of alienation, powerlessness and frustration affected their motivation and their cognitive and emotional processes. The apathy or hostility with which they approached the class contributed to the difficulty the students had in relating to the physics material and in engaging in normal classroom discussion of physics topics.

There is one more contributing factor which must be taken into account: pure exhaustion. Most of the students came to class after a full day of work respon-sibilities and a full early evening of family respon-sibilities. Their passivity and apathy were often as much a result of fatigue as of withdrawal. Hence the class material had to be more than usually motivating to arouse interest. It also had to contribute to a positive self-image for the students as an adequate self-concept is essential to satisfactory educational attainments.

This was the atmosphere in which my first attempts to show the relevance of physics to biology took place. Having been originally trained in biology and chemistry, I found it quite easy to integrate general biological/ medical examples into my lectures. Using hypodermic needles and human skin as an example of pressure instead of thumbtacks and walls as was suggested in the course outline was a sure-fire method for attracting attention. Everyone (especially the nurse's aides) had had some experience with hypodermic needles, and everyone had some opinion on the topic. Psychological barriers diminished as a class discussion developed around the question of how the sharpness of the needle changed the pressure it exerted. Suddenly the physics material was not as remote from their life as they had thought; suddenly they could make a positive and spontaneous class contribution. The students began to make their own connections and to relate to the material from their own perspective: "Pressure? Perhaps this has something to do with blood pressure?" would be a typical comment. The connection between physics and their career choice had become just a little clearer. Once the students saw that physics was a subject useful in the life sciences, they found a resulting interest in understanding it.

Since time was at a premium in these classes, there was not always time for an extended discussion of the biological/medical applicability of a topic. Nevertheless, the students enjoyed having small anecdotes interjected into the basic lecture material. Many commented that the anecdotal material created just enough change of pace to pull them out of the torpor which overcame them by nine p.m. One of them commented, "That statement about the effect of high voltage electrical lines on male sperm count certainly gave me a jolt. Ha!" The point is not the pun, but the fact that the student suddenly had a renewed interest in the class.

Observing how successful the few examples were that I had at my finger tips and realizing how limited my medical information was, I began to gather material that would allow me to expand this approach in the evening classes. As the material was accumulated and sorted into the various categories (see p. 41), I found that the type and amount of material that could be used in adult education was much more limited than that which could be used in the day classes. The adults responded to visual and aural communications, but not so much to written material. Although no testing of the adults was done, they were probably at the concrete operational level in physics since they responded very positively to anything they cauld see or handle. Photographs, illustrations from magazines, models and demonstrations were much appreciated while formal operational students would have been just as satisfied with problem solving on the blackboard. Some examples of the material to which the students responded favourably are: (a) photographs of people on snowshoes, ptarmigan with their feathered "snowshoes" and caribou with their extremely broad feet were used to show methods of distributing a force over a wide area to reduce pressure between solids (Greenberg, 1975: 300-301); (b) an illustration from Natural History showing the prismatic cornea of *Dialommus fuscus*, a unique eye structure that enables the fish to see sharply in both air and water (Stevens and Parsons, 1980: 66); (c) the large scale biological models of the human eye and human ear which could be handled and manipulated by the students and (d) the demonstration model of the human chest which consists of two balloons in a bell jar with a plastic "diaphragm" at the bottom.

Some reading material was acceptable if it could be provided in excerpted, pre-digested form. Greenberg's chapter on pressure was especially successful when used in this fashion. He discusses Pascal's Law in relation to deep-sea divers' chests and ear-drums, in relation to water mattresses and in relation to the foetal sac. The effects of the buoyant force on jellyfish, octopi and fish (with their air sacs) and on the human brain floating in the "sea" of brain fluid are also discussed (1975:292-322).

The students had little time and little inclination to become involved with long articles from magazines, with term papers or with special projects. Small newspaper articles were used in class as interest items. They were usually handed around at or before the beginning of the class while there was no formal teaching occurring. It has been suggested to me that I use the magazine articles in much the same way. Peter Landry (personal communication) found that teachers in his university courses responded very positively to a non-structured technique in which magazines with pertinent articles were simply distributed on his desk at the beginning of class, were available for examination at the students' leisure, and were signed out on loan for a day or even longer by filling out the title of the magazine and the student's name on a sheet at the desk. I have never tried this, being afraid to lose the original copies of the magazines, but I can see that with responsible adults this could be a solution.

Day School Classes Discussed in Detail

The first attempt at innovation in the day school classes was the integration of biological/medical topics into the regular term paper list, e.g., "The Eye as a Physics Object, " "The Ear and Sound Waves," and "The History of Optics as it Parallels the History of Biology." This did not prove very successful. The topics were too broad, and the students found it too difficult to limit themselves. The results were poor, with term papers being thinly disguised encyclopedia articles or book reviews showing minimal student involvement.

The next attempt at innovation involved articles from <u>Scientific American</u> which were made available to the students as photocopies or offprints. Articles such as "Physiological Effects of Acceleration (Rogers, 1962)," "The Human Body in Space (Haber, 1951)," "Medical Thermography (Gershon-Cohen, 1967)," "Man Viewed as a Machine (Kemeny, 1955)," and "The Energetics of the Bumblebee (Heinrich, 1973)" were chosen for their appeal to the average science student. However, without help and guidance, the students were neither motivated nor interested enough to make good use of the material. In addition, the students found the reading level a bit too high, and they tended to view the articles as physics articles rather than as biological articles and, therefore, as less intrinsically interesting.

While I was working unsuccessfully on these larger projects, I was amassing a collection of small facts, photographs and diagrams, and articles from popular magazines and newspapers. I found that the classroom discussions were greatly enlivened by the incorporation of this biologically/medically oriented material into the physics topic of the day.

For example, if we were working on velocity, the students found the following material very stimulating to use as information: the fastest fish is the Atlantic sailfish at 68 miles per hour (McWhirter and McWhirter, 1971: 67) and the fastest snake is the black mamba at 7 miles per hour (Ibid., 70); the fastest cockroach moves at 7 feet per minute (Science News, 1981: 270); and the speed-eating record for fish has been set by the anglerfish which can create one mouth expansion and prey engulfment in six milliseconds (Science News, 1979:249). Another topic, elastic deformations due to forces, is shown in a high-speed photograph in the PSSC Physics text (Haber-Schaim et al., 1971: 304) which showed the distortion of a tennis racket and ball in contact with one another. But how infinitely more interesting to see the large distortion of challenger Ronaldo Snipes' face and of Larry Holmes' boxing glove as shown in a photograph from the sports section of the Montreal Gazette (Appendix 1).

Whole articles from the local newspaper such as "Cool Water - The Fun, Fear and Physics of Swimming (Oberdorf, 1977)" and "In Search of the Mind's Eye - Psychic research has left the tea room and entered the physics lab (Dewar, 1977)" were made available for perusal during free minutes in class. The students appreciated these articles since they were neither too long, nor too technical and were handed out to the class when a relevant topic was being discussed.

In general, the students appreciated having these little bits of enrichment material sprinkled throughout the core physics material and often retained this anecdotal material.

I also had success in using homework problems and test questions which reflected a biological/medical orientation. The typical PSSC Physics end-of-chapter homework question about the pedestrian running for the bus is just as successful when presented by MacDonald and Burns as a cheetah running for a gazelle. Both questions are reproduced below for comparison.

> A pedestrian is running at his maximum speed of 6.0 m/sec to catch a bus stopped by a traffic light. When he is 25 meters from the bus the light changes and the bus accelerates uniformly at 1.0 m/sec^2. Find either (a) how far he has to run to catch the bus or (b) his frustration distance (closest approach). Do the problem either by use of a graph or by solving the appropriate equations (Haber-Schaim et al., 1971: 194).

> A cheetah can accelerate from rest at 8 m/sec^2. If it takes off after the gazelle of the previous example, and if the gazelle bounds away at the same time when the cheetah is 18 m distant from it, how long will it take the cheetah to catch the gazelle? How far will the gazelle have run before it is caught? How fast is the cheetah moving at that instant (MacDonald and Burns, 1975: 57)?

Test questions can easily have animals substituted for the typical laboratory carts, e.g., "A bottle-nosed dolphin can increase its velocity uniformly from 1.0 m/s to 8.0 m/s in five seconds. Find the distance it traveled in that time." Even small take-home laboratory exercises were popular when they dealt with the human body, e.g., "Find the volume of your body," "Find the surface area of your body," "Find your maximum speed," or "Find the near point of your right eye."

As this collection of facts, illustrations, and articles grew, I began to organize it into the following categories:

A. Lecture Material;
B. Reading Material;
C. Problems for Homework, Classwork and Evaluation;
D. Demonstrations;
E. Laboratory work;
F. Term Papers and Special Project Topics;
G. Bulletin Board Material;
H. Career Material.

The lecture material, problems, demonstrations, laboratory work, and bulletin board material were easily integrated into the regular physics course provided that time was available. The reading material, special projects, and career material were not. At first I handed out the readings as I came to the relevant topic in class, and I announced the special projects and term papers in the same way. Beyond an initial response, little enthusiasm was generated by this method. The term papers created special problems in that the more specific topics required more specific references. The special references for the biologically-oriented papers were often not available in the school library, and the students had no access to the more technical libraries in the city. Special efforts were made by some students. For example, one student used his brother's student card to gain access to the McGill University

Medical Library in order to write a term paper on "The Cystoscope." Another student used the library available in her father's office at Hydro-Québec to write a paper on "Power and the Environment" which described the effect of the power lines on the health of the people living beneath them. However, it soon became apparent that not all students were able to do all projects due to the lack of availability of material. To remedy the situation, all relevant material should be available in the school library to allow the students equal opportunity to work independently.

Making the material available in the school library depended to a large extent upon organizing what had been collected. A vertical file was started in the library which was based on typical topics from a layman's point of view (e.g., cryogenics, ultrasound, or bio-luminescence). This file had a two-fold purpose: to organize the large amount of material that had been collected and to allow easy access to the material for students working on various assignments. This system was used for one year, and at the end of that time the students voiced two major criticisms. One criticism concerned the lack of guidance within the topics. There were no indications of the level of difficulty of each article, nor were there any indications of the physics background required for comprehension of the material. For example, one student complained that she had spent a significant amount of time trying to understand the material on ultrasound before realizing that she really should have waited until the class had finished the unit on waves. The second major criticism concerned the quality of the material: the photocopied material was not visually interesting and, therefore, tended to quell the initial enthusiasm.

During this time, I brought Jearl Walker's Flying Circus of Physics (1977) into class and had some success with it. Some students responded immediately to his technique of posing a small problem and then of listing references for further investigation. The appeal seemed to be in two areas: the questions or investigations seemed bounded enough to be digestible with a reasonable amount of time and effort, and the appropriate references were stated in the book making less initial research necessary.

One student had been reading an article from Science News called "Will the Real Nessie Please Stand Up?" (Bartusiak, 1979:122-123) which attempted to relate optical illusions to atmospheric refraction. The student was also interested in psychology. Hence he was excited by the problem posed by Walker:

> Probably the most striking illusion in the natural landscape is the apparent enlargement of the moon when it is near the horizon. Is this illusion brought about by refraction due to atmospheric conditions or is it a psychological effect? (1977:149).

The student wanted to start immediately, but unfortunately, of the four references listed (one from _Scientific American_, two from _Science_ and one from _The American Journal of Physics_) only one was immediately available in the library.

Another student who was at the time interested in optometry (she is now studying podiatry) found the formation of colours by interference fascinating. She was particularly interested in:

> Why are the wings of butterflies colored? Are the colors due to pigmentation? In some wings, yes, but in others, such as for the _Morpho_ butterfly, the colors do not arise from any pigmentation. A possible clue to their origin may be found by looking at a wing from several different angles: the wing takes on slightly different colors from different viewing angles. Why? (Walker, 1977:137)

As an added stimulus, she almost immediately found a picture of a _Morpho_ on the cover of an _International Wildlife_ (Sandved, 1981), and a tray that her grandfather had brought back from South America on which a beautiful design had been created using _Morpho_ wings. However, again, the references listed (_Nature_, _Science_, _Journal of Applied Physics_, _Journal of the Optical Society of America_ and _Journal of Physical Chemistry_) were not available in the school library.

In both of the above cases, I went to the McGill University science libraries myself to photocopy the material since the students had no access to the specialized libraries. The students finally handed in excellent papers on these topics with the added bonus that the student working on the butterflies produced a colourful bulletin board display. However, the time lag between the initiation of the idea and the final gathering of all the resource material was long enough to be annoying.

An assessment of the above difficulties led me to the conclusion that not all material was equally acceptable or useful. The criteria used in selecting appropriate material should include the following: (a) the topics should be narrow in range and clearly defined; (b) the material should have the proper approach, i.e., from the biological or medical side; (c) the reading level and physics level should be appropriate for concrete operational level students; (d) the material should be available at the appropriate time in the course; and (e) all reference material should be readily available in the library in its original form, if at all possible (i.e., with all its visual appeal intact).

With these criteria in mind, a major restructuring of the vertical file was done. In order to insure that the students would have some idea of the level of the material and of the material's appropriateness to the course content, the vertical file was reorganized by subject headings which matched those of the textbook. Hence the first topic the student encounters in the vertical file is: "How Light Behaves" with sub-topics "1. Sources of Light; 2. Transparent, Colored, and Opaque Materials . . . etc. (Haber-Schaim et al., 1971)." Therefore, the student has only to check the section under which the material is filed to know whether or not she has been exposed to the physics on which that material is based.

At the same time, topics were discarded for which no references could be kept in the library. Whenever possible, the original magazines or textbooks were placed in the library rather than the photocopies. Newspaper articles were filed in either the original form or as a photocopy. Small introductions were written to some of the articles to give the students an idea of the contents and, in some cases, of the level of difficulty. Of the original eight categories (see p. 44), I found that the lecture material, the reading material, some take-home labs, special projects, the term paper material and some bulletin board material could be incorporated into this scheme. The career material was kept in a separate folder in random fashion. The problems, demonstrations and laboratory work were, on the whole, relegated back to me. It remained my problem to incorporate those materials into the regular classroom work.

At the beginning of the next school year, the students were taken to the library and were shown the reorganized material. The relationship between the topical outline in the textbook and the topical outline in the vertical file was emphasized. It was also stated that this material was available for enrichment purposes only; nothing was compulsory, everything was available to be used if and when the student felt motivated.

The results of this attempt to make the enrichment material available to the students were slightly encouraging. Using the librarian as my informant, I found that the material was used a great deal at first, but as the work from the other courses built up, the usage declined dramatically. After November, the main use of the material was for relaxation. When the students had a free period (i.e., when a teacher was absent and no substitute was available) or a boring lunch period, they would skim the material for an interesting article and spend twenty minutes on the average with the material. They tended to concentrate on the topic being discussed in class, and they enjoyed having extra information to share with the class. At the informal evaluation session at the end of the year the students were asked why they did not spend more time working with the material. The answers reduced to the fact that there was no incentive (i.e., no external rewards).

Therefore, for the following school year, I set up a credit system whereby the student, during the course of the year, had to do a certain amount of work with the enrichment material. This work was divided into two parts: a compulsory section and an optional section.

Each semester (of which there are four per year) the student had to accumulate a minimum of twenty points in order to maintain her letter grade for that semester's report card. If the student did not accumulate the twenty points, she was dropped one letter grade on that report card. For example, an "A" student who did not fulfil the twenty-point requirement for the first semester received a "B" for the first semester grade.

The optional section gave the student an opportunity to improve her physics grade by working with the enrichment material. For every forty extra points that the student accumulated, her semester average was increased by one percentage point. For example, a student with a 79 average (a "C" on the report card) could change her average to an 80 (a "B" on the report card) by accumulating forty points from the enrichment material.

A typical topic from the enrichment material is reproduced in Appendix 2. Each question from the reading material was worth one point. The laboratory work, term papers, and other large projects were, in general, worth ten points maximum, although this was open to negotiation depending on the complexity of the project. Each student had a five-by-eight index card on which to record the work done. The card was initialed by me as each task was completed and the total number of points accumulated was recorded. This bookkeeping was done outside of class time (i.e., recess, lunchtime, before or after school).

The system was well received. The students did not find it difficult to accumulate the compulsory twenty points each semester, and those who worked for the optional points felt rewarded for their efforts. The students who were particularly motivated and who felt particularly pleased with the optional work were those whose averages were one or two percentage points away from the next higher letter grade, as in the example given above. They were pleased to be able to change their letter grade by doing some extra work. The students also commented on the type of material available in the enrichment material. Those interested in biology/ medicine found almost all the material relevant, and the others found sufficient material of general interest to satisfy them.

This reorganization of the material worked well for me also. Having the enrichment material organized as the course material was organized allowed me easy access to the enrichment material. I had only to go to the vertical file, look up the relevant section and within minutes I had a full page diagram of the hearing process, showing the sound waves entering the canal of the outer ear, being condensed by the canal and being conveyed to the tautly stretched eardrum which then begins to vibrate (Stevens and Warshofsky, 1965:39). Or I could pick out an interesting piece of data for use on a class quiz, e.g., the terminal velocity for a 75 kilogram woman is 140 miles per hour (Benedek and Villars, 1973:2-60). Or I could pick out an article to give to a student who had just asked about the veracity of the facts stated on a television special about the Three Mile Island nuclear installation, e.g., "Health Risks of Nuclear Power" by B. L. Cohen (1978). The point of these three examples is that I could find just about any material I needed in a very short amount of time.

I also found that having to assign points to the various tasks caused my requirements to become much more specific. Instead of a vague, "Read this article and see what you can get out of it." the student was presented with a list of questions which provided her with objectives while reading. There was greater retention of the material when the student had an objective in mind and had to write down the answers to certain questions, rather than just to peruse the article.

In addition to the above mentioned positive results of my attempt to integrate biological/medical material into the physics course, four unexpected fringe benefits were noticed: (1) the students' vocabulary was significantly increased; (2) the students' scope of reading material was significantly extended; (3) the students' concept of the place of science in history and in our culture was enhanced; and (4) the students' interest in physics outside of the physics classroom was noticeably improved. These four fringe benefits will be discussed below.

(1) It had been obvious for some time that concentrating on one textbook led to a narrowness of vocabulary that was detrimental to the student especially when faced with multiple-choice questions on the matriculation examinations or on the achievement tests. One particular example involved the use of the word "monochromatic." This word is not used in the students' textbook at all, but it is frequently used on the matriculation. If the word were not mentioned in class, the students were at a considerable disadvantage. Therefore, it was very pleasing to find that the students recognized many of the words from their readings and even sometimes ventured to use these words in class discussions, hence enriching their vocabulary even more than I had expected.

(2) The expansion of the students' perceived boundaries of reading was another unforeseen benefit. Since an attempt had been made to provide the original article as often as possible, the students usually had to leaf through a magazine or textbook to find their particular reference. They often became interested in, and read, other articles from the same magazine or text-

book and would, therefore, read much more than they had originally intended. They themselves often expressed surprise at the number of articles interesting to the layman that could be found in the science magazines. They also began to recognize the various magazines on the newsstand and would buy the current issue of a magazine which they had previously enjoyed. A few convinced their parents to subscribe to one of the more popular science magazines, thus introducing a science magazine into the home. One boy bought his family a subscription to Discover as a Channukah present.

(3) The enrichment material also provided the students with information about the historical interactions between the sciences and the interactions between the sciences and the culture in which they are embedded. This type of material was especially important to these students since the physics course that they were taking placed no emphasis on this type of material.

(4) Lastly, the students seemed to relate to the material in a way that they had not done before. Many were eager to find out more about their newly acquired information. They became alert to these topics in newspapers or in magazines and often brought in articles to share with the class unsolicited. Other students volunteered to augment the material on file by

donations of related material. For example, one student brought in photographs of an ulcer taken by an instrument that uses fiber optics technology (made available by his gasteroenterologist father) while another student brought in some actual optical fibers (supplied by his brother who works for Bell Canada - Research Division). This type of involvement of community resources was unexpected but appreciated.

Section IV: A MORE SPECIFIC DESCRIPTION OF THE ENRICHMENT MATERIAL AND STUDENT REACTION TO IT.

A. Lecture Material

Under the heading of lecture material, I originally included facts or topics with which I felt conversant enough to be able to introduce into the flow of classroom patter without a break to look at notes or to make special preparations. I could, for example, during the introductory lecture on optics, introduce bioluminescence and give a two or three minute information-packed "mini-lecture" on this topic based on the material that I had collected. This mini-lecture was completely under my control and did not interfere with the core curriculum. Slow-moving or noisy classes rarely heard these mini-lectures. Although this material was specifically labeled "not for evaluation" (i.e., it would not be on the tests), the students retained it and often discussed the material at home. This is evidenced by the fact that younger siblings of the day school students would often ask, "Is this the year that we learn about fireflies?" or "When do we get the lecture on sun-tanning?" Examples of mini-lectures in the optics unit include: (1) Some biological molecules and their response to various wavelengths of the electromagnetic spectrum; (2) The index of refraction of protoplasm as compared to Canada balsam; (3) Optical illusions and atmospheric refraction; (4) The human eye as a physics object; (5) Focusing devices and "other eyes"; (6) Animals and their reactions to different parts of the electromagnetic spectrum; and (7) Tanning, sunburn and the ultraviolet. These topics were found to fit nicely into the optics unit. The students saw their relevance immediately and usually understood the material. I was able to be succinct but informative and could continue the discussion after class if the students so desired. Further information was readily available in the enrichment material in the library, so that the readings often formed a natural continuation of these mini-lectures. Two mini-lectures, one on Bioluminescence and the other on Animals and Waves, are included in Appendix 3.

B. Reading Material

The sources for the reading material were books, magazines, newspapers and a few term papers (written by former students and by me). The general criteria for an article were that it should be visually stimulating, current, have an appropriate reading level and physics level, and a broad perspective.

Free use of dictionaries and encyclopedias was encouraged. As many physics textbooks as possible were made available, especially those written with a biological/medical orientation, in an attempt to show the students that these topics could be incorporated into a normal

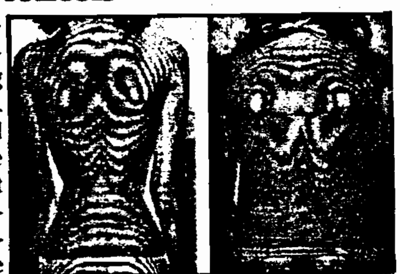
physics curriculum at higher levels of education.
Other textbooks were made available if they contained material that the students needed to answer questions in the enrichment material (for sample questions, see Appendix 2). For example, a mycology text was included for its description of foxfire (luminescent fungi) (Alexopoulis, 1962:508-509) and a biochemistry text for its description of biological molecules and their interaction with light (White et al., 1964:812-824). Regular library books were often shelved in this section if they dealt exclusively with a topic of interest, e.g., Bioluminescence by Klein (1965).

The magazines used were those on a typical secondary school library's subscription list. These included Scientific American, Science News, Discover, Science 81, Natural History, National Geographic, National Wildlife and International Wildlife. Most of these magazines are written with the intent to bridge the gap between science and the layman, hence the articles have broad appeal, are richly illustrated, and are written on a level that secondary students can comprehend. Articles from scientific journals (e.g., Science, Nature, or American Journal of Physics) were photocopied as required, stapled into manila folders and filed with the newspaper articles. The newspapers most frequently used were the Montreal Star, the Montreal Gazette, and the New York Times.

It seemed that the best way to introduce the student to the reading material was to assign the newest and/or best illustrated and/or shortest article first. This enticed the student into an interest in the topic so that the more technical articles, and the longer sections from the books often followed. Another important aspect of a smooth introduction to a topic was the establishment of a basic vocabulary. An understanding of the words used in the article was essential to the comprehension and retention of the material. Appendix 2 illustrates the use of an up-to-date and well illustrated magazine article (Shodell, 1982) to introduce the topic of spectral colours, the establishment of a basic vocabulary for the student, and the gradual introduction of more technical aspects of the phenomenon along with the necessary references for the more difficult material.

The article on scoliosis (Science News, 1978), reproduced below, is an example of the type of very short article that the students liked. Running to about one-hundred words, it takes only a few minutes to read. The students were required to define the words: scoliosis; diagnostic; topographic; delineate; contour; symmetry; and moiré pattern as these words related to the article. The students then had to describe the relevance of this article to the section in their text which described the formation of shadows. The student reaction to this article was positive: they commented specifically on its brevity and its novelty (no-one suspected that shadows could be used in this fashion). A few students also commented on the appropriateness of the topic since there had been at least two children in the school who had been operated on to correct this condition. It was the students who were most aware of scoliosis as a health problem for adolescents who were motivated enough to follow up on this short report and to read the original article from which this report was taken.

The fringes of scoliosis



Scoliosis is a spine-deforming disease of unknown origin afflicting one in ten children. About 10 percent of all victims need corrective treatment to prevent major spine-straightening surgery; early detection and treatment are the key. Physicists with the Canadian National Research Council's Photogrammetry Section have collaborated with an orthopedic surgeon in the design of a simple, low-cost diagnostic technique, according to NRC's SCIENCE DIMENSION (Vol. 10, No. 3, 1978).

An individual is positioned behind an illuminated screen strung with parallel, uniformly spaced, black nylon strings. Light passing through the screen sets up a pattern of shadows which appear on the back. Called a moire fringe, the pattern can be photographed and studied. Like a topographic map, the pattern delineates back contours. Patterns of a normal spine will be symmetrical from left to right. Asymmetrical ones (like the picture on the right) indicate a deformity.

Under a government grant, Otal Precision Co. Ltd. of Ottawa has made three improved models from the NRC device and will distribute them about Canada and this country to test their dependability and marketability.

The visually stimulating articles usually came from <u>Natural History</u>, <u>National Wildlife</u>, <u>International Wildlife</u> and <u>National Geographic</u>. "Hot Butterflies" is an article from <u>Natural History</u> which manages to combine ten full colour pictures of butterflies with a fully detailed scientific description of the thermo-regulatory strategies of temperate butterflies (Douglas, 1979).

The articles from the newspaper were usually very short, attention-getting pieces. The students enjoyed an article that appeared in the Montreal <u>Gazette</u> in June, 1980. The article, "Electrical impulses can move new artificial limbs," describes in about two hundred words how the electrical signals are picked up by the amputee's arm and are used to operate the prothesis (Conn, June 28, 1980). Therefore, when a complementary article appeared in the same newspaper in 1982, it was utilized as well. This article, "Take two volts forget the aspirin," describes the relaxation of the musculature that could be achieved by low doses of electricity (Kliff, April 17, 1982). These small articles were used in clusters, if possible, i.e., three or four on the same or related topic(s) were made available during a class to show the immediate relevance of physics to biological/medical interests. These articles were also used to show the students that some interesting scientific information that they could comprehend was to be found in the daily newspapers, to broaden their knowledge a little, and to elicit a spark of interest in a topic so that the student could be directed to some other enrichment material.

In a few instances, longer articles have been found in the magazine section of the newspaper, e.g., "Healing Electricity" by Dewar (August 18, 1979) which appeared in The Canadian, the magazine section of the Montreal Gazette. These longer newspaper articles were treated as magazine articles, but the reading level was usually a bit lower than the average magazine article, so the students found them easier to comprehend. The students also appreciated the inter-connections that the reporters made when trying to interest a broad-based readership. Here are one student's comments on this particular article:

> I found the article on Dr. Thomas Becker extremely interesting. His broad area of knowledge in physics and biology have allowed him to develop new theories of regeneration. His work is not only concerned with basic theory in biophysics but also has achieved clinical success as well. . . . Dr. Becker's work has been correlated with certain other biological phenomena such as hypnosis, acupuncture, electronarcosis, the action of some pain-killing drugs and even faith healing. . . . I am sure Dr. Becker will become much better known and we will hear a great deal about his exciting research which merges biology and physics in the future.

The more interesting student term papers were also filed with the reading material. These were not included as part of the assigned work, but were simply there for interest's sake. Included were the student term papers mentioned above: "The Cystoscope"; "Power and the Environment"; "The Moon Illusion"; and "Why Are the Wings of Morpho Coloured?" Also present were some term papers that I had previously written which attempted to explicate the relationship between biology and various aspects of physics: "Modern Physics and Biology"; "Nuclear Energy and Medicine"; and "Some Basic Hydrodynamics and the Vascular System." Besides being intrinsically interesting to the students because they knew the authors, these papers served as models for the students who were attempting to write their own first scientific term paper.

C. Problems for Homework, Classwork or Evaluation.

During my search for material, I found many examples of textbook problems that could be included in the enrichment material. The life and health science textbooks written for physics courses were, in particular, rich sources of physics problems that concentrated on showing a biological/medical orientation. There was a great temptation to use these problems in the enrichment material since they were so readily available and so easily adapted. However, I felt that a large proportion of physics time was already spent on problem solving. The students worked on problems in class, as homework, as review material, on quizzes and on major tests. Most of this problem-solving activity was in preparation for the matriculation examination which usually consists of at least forty-five multiple-choice questions.

Under these circumstances, it did not seem rewarding enough to include problems of any type in the enrichment material. Instead, the decision was made to include as much of the material of a biological/medical nature as possible in the problems that were being done in class, as homework, as review material, and on tests. Therefore, although the physics material in the problems did not change, the data in the problems reflected a biological/medical source. For example, physics problems about pressure used the 22,000 pounds per square inch squirrel's bite as data (Science News, 1978:232), the bacterium's top speed of thirty microns per second was used to generate velocity problems (Science News, 1978:214), rotational motion problems involved the 100,000 revolutions per minute of the ultra-centrifuge as information (Greenberg, 1975:214), homing pigeon's flight patterns were drawn to scale to represent displacement vectors (Bart, 1979:30), and the 1000 cycles per second buzzing of a honey bee turned up in the frequency problems (West, 1979:125).

In addition to the standard quantitative physics problems, discussion questions are also encountered. In this type of question, a broad, open-ended problem is posed, and the students do as much with it as they can. An example of this type of question is the "invisible man" problem:

> The invisible man in H. G. Wells' famous novel of that name was invisible because he changed his body's index of refraction to an appropriately chosen value. What do you think the value was? No one could see him, but could he see anyone? Could he keep the same value all the time, or did he have to keep changing it (adapted from Walker, 1977: 115)?

I have found this type of question very useful in that it often led to a heated discussion among the students. I rarely got involved and rarely provided answers, letting the opponents prove as much as they could on their own. These thought-provoking questions were sometimes included in the enrichment material and were sometimes used in class to stimulate discussion.

There were also many questions available that dealt with material not normally covered in a secondary physics course. For example, the optics section of many of the life science physics textbooks has an emphasis on the concept of lens power (measured in diopters) accompanied by the standard questions and problems on this concept. The concept of lens power is not in itself difficult to understand, but should new concepts like this be included in the enrichment material mainly for the purpose of providing more problems for the students to solve? I felt that there was not enough to be gained by asking the student to struggle with this type of work. Students interested enough would see the material during their reading in the life science physics textbooks and would try to work out the problems on lens power on their own should they be sufficiently motivated. To my knowledge no student worked on a concept just to be able to solve problems using that concept.

D. Demonstrations

The demonstrations that were selected did not become part of the enrichment material, but instead became part of the class presentation. Besides applicability to the material being presented, the amount of time required to present the demonstration was a very decisive factor in the selection. Any demonstration that required a large amount of planning and preparation time, or a large amount of class time was discarded. Demonstrating nerve impulses in plants, such as action potentials in Nitella (Blatt, 1974) seemed very promising until I spent four weeks during one summer with two other people merely trying to get the system to work. Equally deceptive was the fifty-word note in the Physics Teacher which described how to demonstrate the diffraction pattern generated by red corpuscles (Hwu, 1979). It sounded simple until I found that assembling the borrowed laser, the microscope, the fresh blood and the screen just too time-consuming for the benefit accrued.

The demonstrations chosen were those that had few materials involved and which could be done quickly and effectively. The use of a pin-hole to improve sight, for example, can be shown with a piece of cardboard and a pin (Patera, 1978) or with a ginger snap having holes in it (Peter Landry, personal communication). A micrometer set up on a microscope in the laboratory allows a simple and easy demonstration of parallax in the measurement of microscopic objects. Demonstrations using large biological models of the human eye and ear are extremely useful when trying to discuss the physical principles underlying their operation. Although these small ideas may not seem to be exciting, they are actually very stimulating to the students.

E. Laboratory Work

Since there is extensive laboratory work in the present physics course, the only laboratory material selected for inclusion in the enrichment material involved small take-home projects for the students. A large number of these involved kinematics. The objects in the real world seem to be in a continual state of motion - especially hyper-active adolescents - and we can use the same simplifying assumption for humans that we use for inanimate objects (i.e., that by describing how one point moves, we describe how the whole object moves). The path of a runner can be used to describe translational motion as easily as the path of a laboratory cart (or nearly!).

Since the students love to run and to use their wrist "stop" watches, they all enjoy the following experiment: Three students post themselves at equal intervals along the length of the gym. The fourth member of the team is timed as she runs as fast as possible past the three timers. A rotation scheme is set up so that each person on the team has a chance to run and be timed. The displacement-time graphs are drawn for each student and are compared. The exercise is then repeated with the added complications of (a) switching the origin, (b) changing the type of gait used (e.g., hopping, skipping, or roller skating, if that is the fad), and (c) changing the direction of motion. Again displacement-time graphs are drawn and compared. Velocity-time graphs are then drawn for each displacement-time graph, and the students are asked why the velocity-time graphs are all parallel to the time axis. Finally the students were challenged to find a type of motion that would not result in a velocity-time graph parallel to the time axis.

Another simple exercise that the students enjoy working on at home is a variation of "the Old Dollar Bill Game":

> A student suspends a dollar bill by one end so that its midpoint is between the separated thumb and forefinger of his partner. The rules of the game are as follows: the partner must keep her hand stationary, but as soon as the bill has been released, she may catch it between her thumb and finger. If she succeeds, she may keep the dollar (adapted from Benedek and Villars, 1973: 1-53).

After the student has time to acquaint herself with the problem, she is asked how quickly she must react to get the dollar, to calculate her reaction time, and to explain what modifications would occur, if any, if the game were played in a moving elevator. Other shorter laboratory exercises include: (a) calculate your horsepower; (b) consider your leg as a pendulum and find the period of it for relaxed walking; (c) find your momentum change when you run full-speed into a stationary guard on the basketball court. The students relate strongly to these activities which are focused on them.

F. Term Paper and Special Project Topics

The function of the enrichment material in this area was to provide as much information as possible about as many topics as possible so that the student had a great variety to choose from. There were basically two types of term papers (or projects) that the students could work on: guided papers (or projects) or open-ended papers (or projects).

An example of the instructions provided for a guided term peper is shown below. This term paper assignment is from the enrichment material entitled "OPTICS Section 1-1 Sources of Light."

> Select one or more of the following groups of organisms (insects, fish, bacteria, fungi, dinoflagellates, molluscs, crustaceans and/or worms) and describe the phenomenon of bioluminescence in that group.

This description should include:

(a) names (genus, species and common names) of organisms in the group which exhibit the characteristic;
(b) the function attributed to the characteristic;
(c) a description of how the light is produced; and
(d) a description of the physical characteristics of the light produced (e.g., wavelength, velocity, frequency, amplitude, period, and colour).

These guided topics always had references provided for the student in the library. For this particular topic, for example, there were seven references available.

Open-ended term paper topics resulted from a student's interest in a topic that was not extensively covered in the enrichment material. On the subject of sound waves, for example, there were only three small articles available: "Shocking Treatment for Kidney Stones" (Raloff, 1982); "Eavesdropping on Vascular Blow-outs" (Science News, 1977:280); and "Ultrasonic Imaging" (Hill, 1978). Yet a student used these as a starting point for a term paper on "The Use of Sound Waves in Medicine." Another student found the juxtaposition of an article on cryobiology (Miller, 1978) with an article on hyperthermia (Silberner, 1980) intriguing enough to lead to a term paper on "Medical Treatment with Extremes of Hot and Cold." Term papers describing the optics of medical instruments were popular. A few term papers resulted from articles the students found in the newspaper. "Animals watched for telltales on U.S. quake" (Montreal Star, March 23, 1977:E-20) resulted in a small paper on "The Impact of Earthquakes on Animals."

Special topics usually involved book reports (written or oral) or other types of reports to the class. These were not popular as the students shied away from books as being too long and too hard. The few books that were read with any kind of consistency were usually those written specifically for the secondary level student. For example, Waves and the Ear (Van Bergeijk et al., 1960) is a paperback from the Science Study Series which was prepared by the PSSC group for secondary physics students. Certain books in the Life Science Library, as Sound and Hearing (Stevens and Warshofsky, 1965), were also popular.

Other types of special projects evolved from the students' special interests. One student interested in photography tried to photograph images formed by reflection, refraction and total internal reflection. Another student inspired by the Invisible Man discussion, tried to make mixtures of liquids having various indices of refraction which would make pieces of glass invisible.

Recently, the day school purchased four Atari 800 computers. I have already had two requests for special topics which involve writing computer programs to illustrate physics topics. One student would like to build a library of typical physics problems which would have random numbers inserted in the problems so that the answers would never come out the same. The other student is interested in computer graphics and would like to make a program showing the eye and the ray optics involved in the formation of an image. These are in the very early planning stages, and I can only hope that they will succeed.

G. Bulletin Board Material

The bulletin board material included magazine pictures, textbook diagrams, and illustrations from newspapers. The students would sometimes make a poster to illustrate their term papers, and these were also used as bulletin board material. One student prepared a display to illustrate the type of work done by a biophysicist.

Timing in the use of bulletin board material was crucial. The material was most appreciated if it was on display as the pertinent material was being covered in class. For example, pictures of reflections were most appreciated while the class was studying plane and curved mirrors. Pictures illustrating total internal reflection were not even comprehended until the topic had been covered in class. Pictures of *Morpho* butterflies with questions about their colouring were incomprehensible until we had studied colour production by interference in thin films.

H. Career Material

The career material was kept in a separate folder and had very little organization to it. The material ranged from the standard course descriptions from McGill and Concordia Universities to pamphlets about speciality courses at various other universities, e.g., a pamphlet describing a bioengineering program at McMaster University (1975). There were also articles which were intended to give students an idea of careers which could involve both physics and one of the life sciences. Some examples are: "Career Opportunities in Medical Physics" (Hendee and Siegel, 1977); "Physics in Nuclear Medicine" (Elliott, 1978); "Medical Electronics" (Watson, 1978); and "Physics in Intensive Care" (Williams, 1978). The article "Some Historical Interactions of Physics and the Biomedical Sciences" (Whorton, 1974) was included so as to give the student some idea of the background upon which present day practice is built. Sometimes job opportunities from the careers section of the local newspaper were clipped for inclusion in this folder. There was no compulsory work with this material. It was there for interested students.

Although the above description shows the state of the enrichment material at this time, it is not to be inferred that all is perfect. This type of material must be subject to ongoing scrutiny of the old material and to continual renewal with new material. This project must not be allowed to stagnate: part of its appeal is in its open-endedness and its responsiveness to change.

There are other types of changes that must be made in addition to changes in materials. The students are not satisfied with the number of points assigned to certain activities. I am not satisfied that sufficient challenging material is included. The book reports are still a weakness in that they are too vague and disorganized. There are still topics which I feel belong in the enrichment material (e.g., polarized light and its use by the bees and migratory birds) but which have not yet been included owing to lack of time or lack of available references.

Section V: CONCLUSION

In the preceding sections, I have attempted to identify the problem, to justify and to state my solutions and to some extent to assess the results.

The problem was that the student body saw no relationship between the subject that they were required to study in preparation for a career and the career itself. The justification for attempting a solution was the recognition that a teacher should respond to the needs of her pupils. The solution involved an innovation in the physics program in which the student was exposed as often as possible, in as many ways as possible, to the relationship between physics and the biological/medical sciences. An on-going assessment of the results of the innovation led to modifications of procedure but not of basic approach; of form but not of content. The innovation resulted in a clientele that did not experience physics subject matter in isolation; students who did not have their physics information in water-tight compartments; students who could regard their physics knowledge not as a fixed compendium of facts, but as an instrument for understanding and dealing effectively with new fields of study.

Education has always had the tendency to be compartmentalized and fragmented. As the amount of information available has grown, this specialization process has also grown, sometimes to the point of absurdity. In recent times, however, there has been a reaction to this tendency in the form of interdisciplinary fields of study (Hartman, 1976:206). For example, Concordia University in Montreal has established an interdisciplinary Science College for its undergraduate students which has as one of its aims: "To become acquainted with the style and content of the various scientific disciplines " (Concordia University, 1982). The general attempt on the part of such programs is to provide a more comprehensive viewpoint for the understanding of intellectual and social problems.

Alan Watts wrote in defense of interdisciplinary studies in 1966:

> . . . every scientific discipline for the study of living organisms -- bacteriology, botany, zoology, biology, anthropology -- must, from its own special standpoint, develop a science of ecology -- literally, 'The logic of the Household' --or the study of organism/environment fields. Unfortunately, this science runs afoul of academic politics, being too interdisciplinary for the jealous guardians of departmental boundaries. But the neglect of ecology is the one most serious weakness of modern technology, and it goes hand-in-hand with our reluctance to be participating members of the whole community of living species (1966:86).

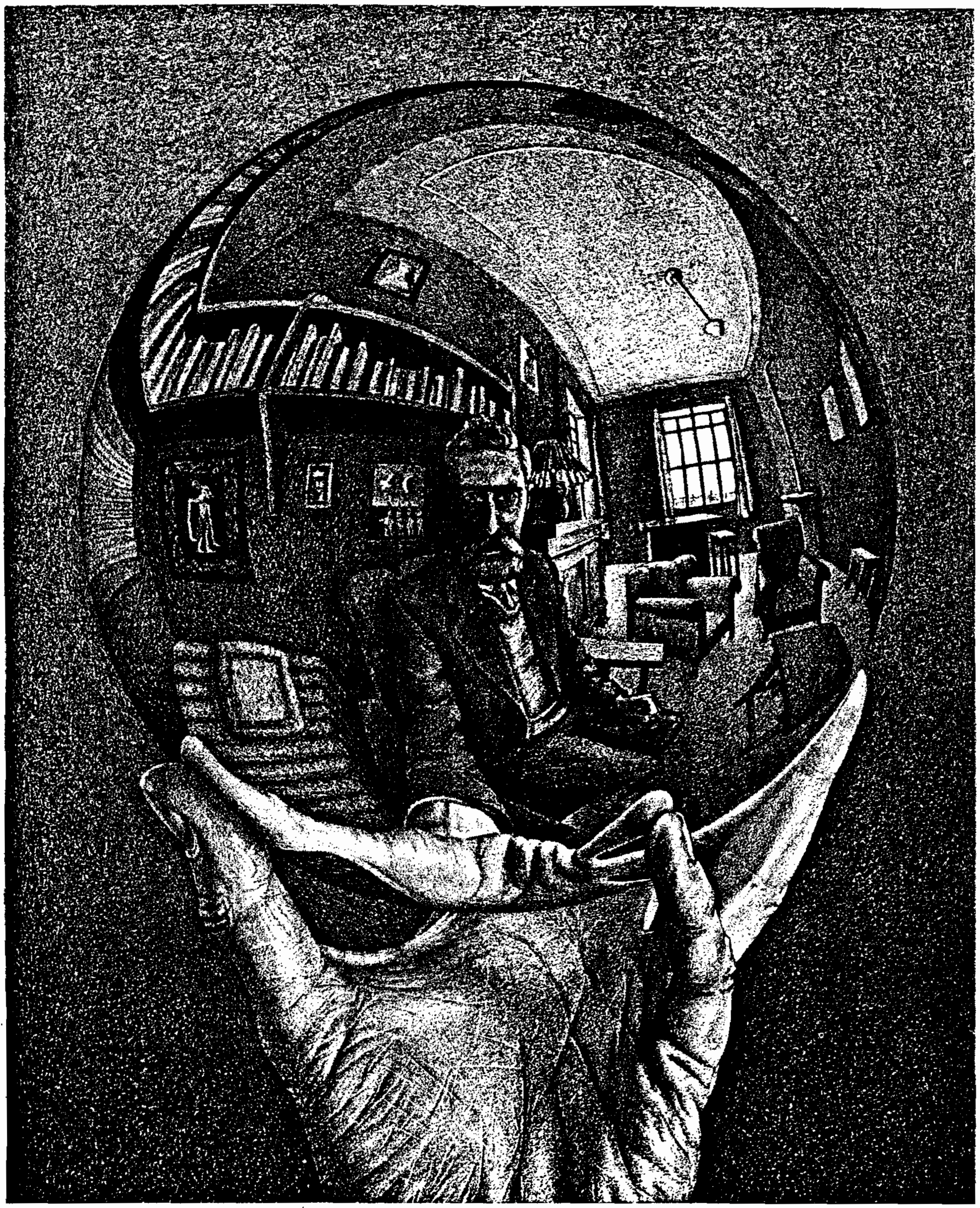
I would extend this "logic of the household" from the disciplines dealing with living organisms to all disciplines. All disciplines exist in an environment, and that environment must at some time be attended to.

When we attend to one subject, our perceptions are narrowed. We perceive the world in bits and pieces, and we try to deal with the world in bits and pieces. But the world is one and somewhere in every discipline we must account for the fact that patterns are sustained although the fragments differ. The Gestalt theory of perception explains this figure/ground relationship by saying that no figure is ever perceived except in relationship to a background. There are great losses in perception when we emphasize the figure to the detriment of the background.

What physics teacher could think to leave the study of plane mirrors without quoting Sylvia Plath's poem "Mirror " (1971:52)?

> I am silver and exact. I have no preconceptions.
> Whatever I see I swallow immediately
> Just as it is, unmisted by love or dislike.
> I am not cruel, only truthful --
> The eye of a little god, four-cornered.
> Most of the time I meditate on the opposite wall.
> It is pink, with speckles. I have looked at it so long
> I think it is a part of my heart. But it flickers.
> Faces and darkness separate us over and over.
>
> Now I am a lake. A woman bends over me,
> Searching my reaches for what she really is.
> Then she turns to those liars, the candles or the moon.
> I see her back, and reflect it faithfully.
> She regards me with tears and an agitation of hands.
> I am important to her. She comes and goes.
> Each morning it is her face that replaces the darkness.
> In me she has drowned a young girl, and in me an old woman
> Rises toward her day after day, like a terrible fish.

Or who would leave the study of curved mirrors without showing at least one of Escher's wood cuts of distortions in a globe?



Who can teach dispersion without touching on the psychological and physiological aspects of colour perception using van Gogh's paintings with their amazing colour schemes which have now been attributed to the effect of digitalis on his perceptions. (Science News, 1981:153). Who can speak of the early work on radioisotopes without speaking of the tragic deaths due to leukemia of many of those pioneers of research on radioactive materials. Who could teach chemistry without discussing the Borgias and poisons or the autumn colouration of the deciduous forests. What biology teacher could teach angiosperm reproduction without reading D. H. Lawrence's sexy description of hazel catkins and buds to her class:

> "Give them some crayons, won't you?" he said, so that they can make the gynaecious flowers red, and the androgynous yellow. . . . There is just the one fact to emphasize."
> . . . "What's the fact? -- red little spiky stigmas of the female flower, dangling yellow male catkin, yellow pollen flying from one to the other. . . ."
> "What are you doing?" she sang, in her casual, inquisitive fashion.
> "Catkins," he replied.
> "Really!" she said. "And what do you learn about them?"
> . . . "Do you know the little red ovary flowers, that produce the nuts? Have you ever noticed them?" he asked her. And he came close and pointed them out to her, on the sprig she held.
> "No," she replied. "What are they?"
> "Those are the little seed-producing flowers, and the long catkins, they only produce pollen, to fertilise them."
> "Do they, do they!" repeated Hermione, looking closely.
> "From those little red bits, the nuts come; if they receive pollen from the long danglers."

> "Little red flames, little red flames," murmured Hermione to herself. And she remained for some moments looking only at the small buds out of which the red flickers of the stigma issued.
>
> "Aren't they beautiful? I think they're so beautiful," she said, moving close to Birkin, and pointing to the red filaments with her long, white finger.
>
> . . . Her absorption was strange, almost rhapsodic. Both Birkin and Ursula were suspended. The little red pistillate flowers had some strange, almost mystic-passionate attraction for her (Lawrence, 1950: 39-41).

These examples to me illustrate the environment in which our various academic disciplines live. The holistic concept of knowledge can be used to combat compartmentalization. David Bohm, the physicist, advocated this world view:

> . . . the world cannot be analyzed correctly into distinct parts; instead, it must be regarded as an indivisible unit in which separate parts appear as valid approximations only in the classical limit. . . .
>
> Although such fluidity and dependence of form on the environment have not been found, before the advent of quantum theory, at the level of elementary particles in physics, they are not uncommon in classical experience, especially in fields, such as biology, which deal with complex systems. Thus, under suitable environmental conditions, a bacterium can develop into a spore stage, which is completely different in structure, and vice versa. Yet we recognize bacterium and spore as different forms of the same living system. There is certainly similarity here to the quantum behavior of the electron, for we can also recognize wave and particle aspects of the electron as different "forms" of the same material entity (1958: 161-162).

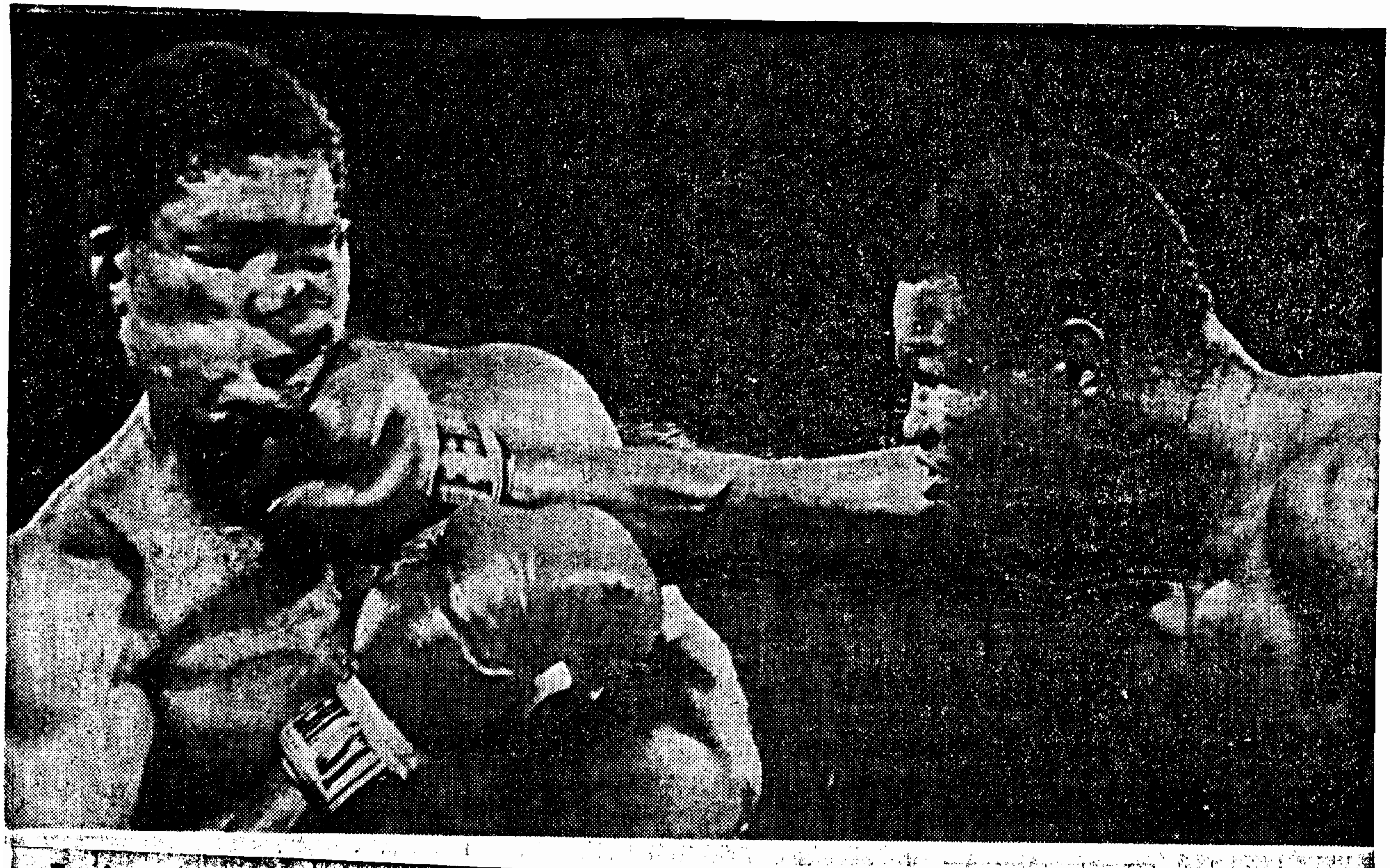
An increased awareness of the sterility of compartmentalization should stimulate teachers to search for relationships between their discipline and the students' environment. Crossing disciplinary borders helps the students to establish a broader framework of conceptualization by the recognition of common aspects and methods of seemingly disparate disciplines. That this has been happening to some extent can be illustrated by a paper by Callen and Shapero, "A Theory of Social Imitation," which purports to apply ferromagnetic theory to such diverse phenomena as schools of fish and flashing fireflies (1974).

The thrust of my innovations has been to highlight the background without losing the detail of the foreground. To, at least, have the students realize that the physics world does not exist in a void, but has real connections to other areas of knowledge.

To what extent have these innovations succeeded? They have succeeded to the extent that the students come to class with a new attitude. They see that the whole world has relevance to physics and that they can be a part of the quest for new information to demonstrate that relevance. They see that they can become resource people, able to contribute ideas and facts as important as those that the teacher has contributed, thus making them worthy members of the community. The innovations have succeeded to the extent that the anxieties associated with the physics classroom have decreased in the atmosphere created by the interdisciplinary discussions; to the extent that fewer and fewer students have found an opportunity to be bored -- the sheer number and range of activities available make it unlikely that a student will be unable to find enrichment material that is interesting and is at her level. These enrichment activities are the environment of physics and they create the background for a course in which the basic knowledge and skills of physics remain inviolate.

Appendix 1

An example of the elastic deformation of a human face.



Toughness is mixing it up under backboard (above), as Boston Celtics' Robert Parish (rear) shows as he outmuscles Houston Rockets' Moses Malone for ball during NBA final, captured by the Celtics. Or heavyweight champion Larry Holmes, right, rearranging the features of challenger Renaldo Snipes during heavyweight title match won by Holmes, who got up off floor to polish off challenger.

Appendix 2

A reproduction of a typical topic from the enrichment material.

OPTICS

Section 3-8: Refraction by Prisms: Dispersion

This section has two types of activities in it: reading material and lab material.

This section concentrates on the phenomenon of dispersion. Before beginning, you should reread the relevant section in the text and answer the following questions:

(1) Define dispersion.
(2) Define spectrum.
(3) Name the parts of the visual spectrum.

In the April, 1982 issue of Science 82, you will find an article entitled "The Curative Light" by Michael Shodell. This article describes the field of photobiology.

(4) Define the following terms which are used in the article:

(a) albinism	(k) dermatologist	(u) phototherapy
(b) anemia	(l) esophagous	(v) premature
(c) ameliorate	(m) fluorescing	(w) propitious
(d) benevolence	(n) jaundice	(x) salubrious
(e) benign	(o) laser	(y) skeptical
(f) carcinogenic	(p) maladies	(z) therapeutic.
(g) carcinoma	(q) neural	
(h) chemotherapy	(r) optic fibers	
(i) degenerative	(s) photobiology	
(j) deleterious	(t) photoradiation	

(5) The article describes a very specific use of blue light in phototherapy. What is it?

(6) The article describes a very specific use of red light in phototherapy. What is it?

(7) How does the author feel about the use of light as a "drug?"

The author of this article mentions a fad of the 1900's which used coloured lights to treat various maladies. A whole theory of healing exists which uses spectral colours as a source of curative powers. Read Chapters One and Two in The Power of the Rays by S.G.J. Ouseley.

(8) On page ten, the author states that "plants grown under red glass shoot up four times more quickly than in ordinary sunlight, and that slower growth occurs under green or blue glass." What would be a biophysical explanation for this phenomenon?

(9) Name the colours used in chromotherapy.

(10) Choose one colour and show what conditions this colour might be used to treat.

Lab Material

On page sixteen, it is mentioned that various organisms respond differently to different colours of light. Set up an experiment which would test for this type of behaviour <u>without</u> harming the organism that you have chosen to test. The aim, materials and method must be checked by me <u>before</u> starting any work. If you have trouble with ideas, try reading <u>Introducing Science Concepts in the Laboratory</u> by Murphy and Schmidt (1977) especially Unit 2: Biology: Living things detect and respond to stimuli.

Again and again, in the textbook and in the above articles, we see the spectral colours (red, orange, yellow, green, blue, indigo and violet) mentioned. We see that these colours arise by separating white light, and that they cannot be separated farther into other colours. Yet we know that other colours do exist -- pink and chartreuse, for example. How do we see those colours? The answer generally given is that the phenomenon of colour depends only partly on the physical world. It also depends upon the eye and the brain which detect and interpret that colour. In one textbook colour is described as the psychological attribute of light and psychophysics is described as the field which investigates the relationship between the psychological and the physical attributes of light (Cromer, 1974:295).

The field of psychophysics was investigated by Hermann Grassmann in the mid-1800's. Grassmann stated that the first law of colour was that the normal human eye perceives only three attributes of light, referred to as brightness, saturation, and hue.

(11) Find the definitions of these three terms in <u>Physics for the Life Sciences</u> by A.H. Cromer on pages 295-301.

(12) Which of the non-spectral colours mentioned above is due to the change in saturation of a spectral colour? Explain.

Notice that according to this view of the phenomenon of colour, each colour can be defined by stating its brightness, saturation and hue -- all of which are <u>psychological</u> attributes.

Grassmann's second law states that any colour can be formed by mixing two other colours.

(13) Which of the non-spectral colours mentioned above is due to the mixing of two other colours? Explain.

As simple as these concepts seem, they led directly to the basis of colour television, colour photography and the understanding of colour blindness, seemingly very diverse topics. If you find this section interesting and would like to do a special project on this material, a reasonable place to start would be to read Chapters 35 and 36 in The Feynman Lectures on Physics by Feynman, Leighton and Sands (1963).

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OPTICS

Section 3-8: Refraction by Prisms: Dispersion

ANSWER SHEET
(To be used by student when unit is complete)

(1) Spreading out of light into a spectrum.
(2) Distribution of energy emitted by a radiant source
(3) Red, orange, yellow, green, blue, indigo and violet
(4) (a) Absence of normal pigmentation in a person, animal or plant
- (b) A pathological deficiency in the oxygen-carrying material of the blood
- (c) To make better; to improve
- (d) An inclination or tendency to good will
- (e) Tending to promote well-being
- (f) Cancer-causing
- (g) A malignant tumor
- (h) Characterized by deterioration
- (j) Injurious
- (k) Doctor of the pathology of the skin
- (l) A muscular, membranous tube for the passage of food from the pharynx to the stomach
- (m) Emitting visible light after absorbing some other incident radiation
- (n) Yellowish discolouration of tissues and bodily fluids with bile pigment caused by any of several pathological conditions in which normal processing of bile is interrupted.
- (o) Any of several devices that convert incident electromagnetic radiation of mixed frequencies to one or more discrete frequencies of highly amplified and coherent visible radiation. (Light Amplification by Stimulated Emission of Radiation)
- (p) A disease, disorder or ailment
- (q) Of or pertaining to the nerves
- (r) A flexible optically transparent fiber, as of glass or plastic, through which light can be transmitted by successive internal reflections
- (s) Study of the dependence on light for the continuance of life and growth
- (t) Visible part of the electromagnetic spectrum
- (u) The treatment of disease, especially certain skin conditions, with light, including infrared and ultraviolet radiation
- (v) Uncommonly or unexpectedly early
- (w) Presenting favourable circumstances
- (x) Conducive or favourable to health or well-being
- (y) Doubting
- (z) Having healing or curative powers.

(5) The blue light causes a structural change in the bilirubin molecule which causes a conversion from the insoluble form to the soluble form.

(6) It is used in conjunction with a porphyrin derivative to destroy cancerous tissue.

(7) "The use of light as a 'drug' to cure disease still is a developing concept." The author seems to feel positive about the possibilities of using light in modern medicine.

(8) Answers will vary:
Red light is absorbed by chlorophyll, therefore, the red light was used for maximum photosynthetic efficiency. The blue-green light is on the whole reflected leading to poor photosynthetic efficiency.

(9) Red, orange, yellow, green, blue, indigo and violet

(10) Red - lack of vitality
Blue - inflammations
Green - Brain and nerve stimulant
Orange - Cold, sluggish or chronic conditions

(11) Brightness: The dimension of a colour that represents its similarity to one of a series of achromatic colours ranging from a very dim (dark) to a very bright (dazzling).
Hue: The dimension of colour that is referred to a scale of perceptions ranging from red through yellow, green, and blue, and (circularly) back to red.
Saturation: degree of difference from a gray of the same lightness or brightness.

(12) Pink: a lighter form of red.

(13) Chartreuse: formed from the mixing of pigment colours yellow and green.

Appendix 3

Examples of two mini-lectures from the Optics Unit of the enrichment material.

Minilecture on Bioluminescence

(Note: the statements in parentheses are the replies expected from the students.)

What are the four sources of light that the text describes? (Sun, stars, lamps and lightning bugs.)

What is a lightning bug? Does anyone know another name for this organism? (An insect; firefly.)

In what course would you normally expect to hear about bugs? (Biology.)

Since these organisms give off light or luminesce and are part of biology, they are often discussed in a course called biophysics. Here are some pictures of fireflies from the May-June, 1982 issue of International Wildlife.

What function could this light play in the life of a firefly? (To see with.)

If they use their light to see with, where would you expect the source of this light to be? (up front.)

Here is an artist's representation of a firefly from The Bug Book. What are the three major parts of an insect's body? (Head, thorax and abdomen.)

From the illustration, which body section is the source of the light? (the abdomen.) It would not seem reasonable then for an insect to produce light with its tail to help it see.

What is another characteristic of this light? (It flashes.)

Why might this fact be important? (Flashing lights can be used to send signals.)

Why might organisms want to signal to each other? (To find each other.)

For what important function do organisms want to find each other? (Reproduction. Giggle, giggle!)

The male fireflies use special signals to attract females of the same species. The females signal back. But if a male or female of one species is hungry, it will switch the signals to those of another species of firefly, and eat the unsuspecting suitor that comes honing in on the signal.

Can you think of any other organisms that might give off light? (There are few answers to this one: one or two adult students have mentioned the "glowworm" from the song, "Glow little glowworm, glitter, glitter." or "things in the ocean." Usually the adolescents have no idea.)

There is a fish in the Indian Ocean called the flashlight fish which is shown on the cover of this Science News, the Feb. 18, 1978 issue. It has a luminescent part just below its eye. This part can be covered by a membrane so that the light can be turned on or off at will. Of what use could this be? It might be of help to tell you that these fish live very deep down in the ocean where it is very dark. (To help the fish see.)

What do the fish need to see? (food and other fish.)

Yes, the fish use the light to see potential prey, potential enemies and potential mates. The fish can signal to each other by moving the membrane up and down. There are many types of marine fish that produce bioluminescence. One type uses it to startle enemies. They let the enemy get up close, flash the light in the enemy's eyes and then take off like a shot. Other fish have soft light on their ventral surfaces (bottom) which help them to mimic the sky and, therefore, be less obvious to the fish below them.

Where does the light come from? (Usually no answer) The marine biologists who study these fish have found that it is not actually the fish glowing, but a certain type of bacteria. What type of relationship is this? (symbiosis -- each organism seems to benefit from the partnership.) Most of the bacteria emit blue light, but a few emit yellow light.

How is this light produced? (no answer) Do you remember from chemistry how an atom could emit light? (The atom has excited electrons which jump from a higher energy level to a lower energy level.) These bacteria seem to have the ability to use chemical energy to produce excited electrons. The blue light is emitted as the excited electron returns to its ground state.

Other marine creatures display bioluminescence. Can you guess a few? (All types of answers are given.) Squid and octopus are two examples. Even plants are known to be luminescent. Who has heard of the alternative lifestyle magazine called "Foxfire?" (Rarely do I get a positive response.) Foxfire is the name given to the phenomena of stumps and decaying wood that glow in the dark. Scientists have found that this glow is caused by a fungus.

There are even algae that luminesce. Who knows what the "red tide" is? (A few recognize that it causes poisonous shell fish) This phenomenon is caused by one-celled algae called dinoflagellates. These dinoflagellates are responsible for most of the light seen on the ocean water at night.

Thus, we see that many types of organisms are able to produce their own light.

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Mini-lecture on Animals and Waves

Animals emit and receive information from their surroundings. They often do this by generating or detecting some type of wave. For instance, humans detect light with their eyes, sound with their ears, and infrared radiation with their skin. Humans can produce sound waves with their vocal cords and infrared radiation with their skin. Some animals produce and detect these same types of waves while other animals produce and detect other types of waves. Not only that but animals differ in the characteristic of the wave to which they respond, for example, dogs can hear sound waves of higher frequency than a human can. Therefore, a knowledge of the various types of waves that exist, as well as a knowledge of the characteristics of those waves will help us to understand how animals interact with their environment.

We can start with the most familiar of waves, the visible part of the electromagnetic spectrum, light. One interaction that occurs is between the light and the retina of the eye. Only three of the eleven major phyla of animals have developed well-formed, image-resolving eyes: the arthropods (insects, crabs, and spiders), the mollusks (octopus, and squid) and the vertebrates (us). In each case the molecule that absorbs the light energy is related to the vitamin A molecule.

The light that hits the retina can also affect the biological clocks found in many vertebrates. Many activities that normally take place at a certain time in the yearly cycle of an animal, for example, migration, reproduction and hibernation, have been shown to be triggered by changes in day length. By artificially changing the duration of the light to which an animal is exposed, the scientists have succeeded in obtaining certain animal behaviours completely out of season. Humans, to some extent, also respond to the amount of light that they receive each day. There has been a connection made between "winter blues" and the short day length. The scientists think that these "winter depressives" actually go into a sort of hibernation - often they sleep ten to fourteen hours a day! The mechanism suggested is exactly the same as that for hibernating animals. The light, acting through the retina and the hypothalamus, suppresses the secretion of melatonin, a hormone normally secreted by the pineal gland at night. The melatonin plays a role in the seasonal rhythm of animals. Although most humans are not sensitive to melatonin variations, the scientists suspected that these winter depressives were. The researchers were able to reverse the depressive behaviour in humans by artificially lengthening the day by flooding their rooms with light in the morning and in the afternoon.

Ultraviolet radiation, also a part of the electromagnetic spectrum, is an important source of information for animals. Although humans are completely blind to ultraviolet, the capability to see that part of the spectrum is widespread in the insect world. For some insects, this sensitivity is extremely important. An ordinary marsh marigold which looks plain yellow to the human eye has radiating lines visible in the ultraviolet which direct bees to the pollen and nectar in the flower. Certain moths have wing spots invisible to the human eye that attract mates by pulsating at ultraviolet wavelengths. Even homing pigeons have been found to have a second peak of visual sensitivity in the ultraviolet range, and are thought to use this sensitivity as a secondary source of information for homing.

Infrared radiation (often called heat waves) can be detected by some reptiles such as the bamboo viper. This snake has delicate heat detectors in deep pits between its eyes and nostrils. These organs sense the body heat of warm-blooded animals and help the pit viper to find its prey.

Sound waves are not transverse waves as those in the electromagnetic spectrum are, but are longitudinal waves. As with light we often characterize these waves by their frequency: low frequency (infrasound); medium frequency (audible sounds); and high frequency (ultrasound). Each type of sound wave has its place in the animal world. Everyone is aware of the audible sounds produced by living creatures. Much work has been done in observing, recording and classifying the various sounds made by various organisms and in trying to identify the meaning of those sounds. How do we begin to communicate with a whale? We study her sound patterns, try to connect a pattern with a behaviour, and then play back that sound pattern to the whale to see if the same response is elicited. Much of today's research seems to be on trying to attune ourselves to the animals' waves and its characteristics, rather than trying to attune the animal to our waves and characteristics.

What about infrasound? What possible information could an animal receive from low rumbling noises, as low as three cycles per minute? These are the types of sounds generated by oceans, major thunderstorms and winds as they blow over major landforms like the Rocky

Mountains. We refer again to the homing pigeon. It can detect this type of wave and use it as a navigational aid.

The most common example given for the use of high frequency sound is echo location by hunting bats. The bats emit a short burst of very high frequency sound as they fly through the air. As the sound hits objects, it is reflected and the returning signal (an echo at 61 kilohertz) is received by the ear and processed in the bat's brain. The processing tells the bat the position and speed of the moving target. As an interesting response to this use of sound to find prey, at least one type of prey has developed a method to elude the hunter. A type of cricket has been found which has a single pair of nerve cells (one on each side of the body) which is stimulated only by the frequency of sound used by a hunting bat. The functions of these nerve cells are actually inhibited by the sound frequency used by other singing crickets. When the cells are stimulated by the high frequency sound, they send a message to the brain which stimulates certain muscles which cause the cricket to immediately fly away from the sound source. The whole procedure takes less than a tenth of a second!

Even wheat can respond to high frequency sound. A Canadian botanist found that wheat growth could be stimulated by up to 300% by being subjected to high frequency (5000 Hertz) sound over several weeks.

What about simple mechanical waves or vibrations set up in strings as we saw in the laboratory? Do any animals respond to this? Yes, the spider. The web carries the wing vibrations of trapped, bussing flies to the spider. The spider attracted to this type of vibration, pounces on and paralyzes its prey. However, this is not the only kind of vibration that the spider responds to! The male spider uses special vibrations (or drummings) as part of his courtship behaviour to attract the female. He has to be careful or he might be eaten!

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