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ABSTRACT

The characteristics and differences between the various approaches to utilizing environmental themes and issues in college physics classes are reviewed in this paper. These physics courses are grouped into three categories: introductory level, upper level, and seminars. The upper level courses generally involve the application of rather sophisticated physics and mathematics to the understanding of environmental problems. Two categories of introductory level courses are recognized: one kind attempts to familiarize students with current environmental problems as its main goal and the other has goals more closely related to traditional physics, with the understanding of environmental problems being secondary. Examples of these approaches are described, including the author's course, "Energy and the Environment," at the University of Maryland. A short bibliographic resource list useful to prospective course designers is provided. (PR)

THE ENVIRONMENTAL THEME IN PHYSICS EDUCATION

Talk delivered by John M. Fowler
at the
Annual Meeting of the APS-AAPT, 31 Jan. 1972

In the late forties or early fifties there was a terrible blizzard in the midwest one January which buried states like Kansas and Nebraska in deep snow. Nine months later in September the doctors in that region noted a sharp pulse on birth statistics. As I looked at the program of this meeting I see evidence that some births stimulated by Earth Day of a year and a half ago are now being reporte . I don't know whether we are observing a pulse in "environmental course," but some physicists have discounted such courses as temporary fads. I don't think they are, or more accurately, I hope they aren't; I believe that they have in them the ingredients of a kind of course that physics needs.

You have heard and will hear specific examples of environmental courses on this morning's program. What I want to do with my talk is to examine the birth statistics which I have available to me and spend my time telling you something about the average characteristics of this type of course as well as some of the important benefits they can have for physics education.

What I want to do then is to give a summary of the kind of information I have gathered and to try to analyse the differences between the various approaches. I will also list some of the bibliographic resources available to prospective course designers and say a little bit about a course I have been working with at the University of Maryland. But before I enter into this program, let me anticipate a broad question, and one that I have been asked in many different forms. "Why should a physicist (or a physics department) offer a course that departs so far from the traditional content of physics?"

There are several answers to this kind of question. One of the reasons surely has its roots in "enlightened self-interest." The weakening of the distribution requirements, that has taken the shine from pure physics, and the general turning away from science which has characterized the present student generation, all have contributed to reduced enrollments in physics. To attract students back into our courses we must, so the wisdom goes, reach out for them and package physics in a way that emphasizes such involvement as it has with everyday affairs. As one of my correspondents said, "You may buy them (for a short while) by wearing an ecology button and shouting environment."

From his phraseology you can gather he didn't approve of this motivation. Put so crassly, I don't either. We should not design courses solely from the point of view of attracting students; we are not in the cafeteria business. It remains, I believe, a faculty responsibility to decide what the educational goals of a course are and to design to these specifics. The position I want to put forward is that proper goals for a certain set of students will be better met by a course designed around an applied theme than by the traditional course organized around a set of sequential ideas from physics theory. And I believe the environmental theme is a good applied theme.

As a background paper for the Commission on College Physics Conference on Priorities for Undergraduate Physics Education we compiled descriptions of some 50 or 60 physics courses and seminars with an environmental theme. From additonal correspondence it is certain that there are more underway. It may be true that some of our colleagues who have established these courses have done so from strictly market considerations. Given the pressures in many physics departments to improve student to faculty ratios, one can't be too critical of this approach. But there are deeper reasons which surely lie behind the development of many of them.

There is, I believe, a strong feeling on the part of many physicists that the presentation of physics at the beginning level must do more than it has in the past to show the kinds of contributions physics can make toward the solutions of some of the immediate problems of society and toward the preservation of a certain quality of life. We, who feel this, recognize however that it is not so much the content of physics that must be presented to these non-science students, but rather what I have called elsewhere the "process" of physics. It is this reasoning that lies behind the design of many of the courses I will report.

A second concern which lies behind the development of these courses is, I believe, the feeling that physics instruction at the undergraduate level has become increasingly narrow and increasingly theoretical, so much so that it no longer reflects the breadth of physicists or of physics as it is practiced. Courses which show the application of both the content and processs can give students a perspective on physics that alters the present image.

For whatever the reason, environmentally-oriented courses are being taught and their numbers are being added to.

WHO IS DOING WHAT, WHERE?

I will not attempt here a complete description of every course in the CCP files. An annotated listing of these courses was prepared for the aforementioned Priorities Conference and will be published as an appendix to the full report of this conference -- an event I anxiously look forward to. This is a preliminary report of that summary.

In summarizing them here I will take two different cuts through the collection. I will first categorize them by audience and approach. I will also report to you on their goals as I see them and on the physics content and processes which can be developed under these themes.

Generally, three kinds of courses have been reported: introductory level, upper level and seminars. Let me deal with these two types first.

Upper Class Courses

There are now several examples of upper-class courses which apply rather sophisticated physics and mathematics to the understanding of environmental problems. Marc Ross at Michigan has pioneered one of these, "Technology Assessment," which was described briefly in Newsletter #24. A reproduction of the course outline is shown as appendix 1. This course has appealed not only to physics majors but to upper-class students from the other sciences and from the social sciences.

Robert Williams, also at the University of Michigan, has used the environmental theme in a different way. He is teaching the regular thermodynamics course for physics majors but has shifted the emphasis toward statistical physics and organized it around environmental applications. As samples of topics which are thoroughly investigated he lists:

Thermodynamics of Moist Air
The Microphysics of Clouds
Nucleation Processes in Clouds
Droplet Growth by Diffusion
Droplet Growth by Collision and Coalescence
Pollutant Emission and Condensation/Precipitation Phenomena
Electric Power and Thermal Pollution
Space Heating Options (Analyses heat pump)
Greenhouse Effect
Heat Balance and the GNP
Desalination of Sea Water

A third example of an upper-level course was provided by Prof. Jerry P. Gollub at Haverford College. "Physics of the Earth and its Atmosphere" was taught to students who had completed an introductory-level course at the level of the Berkeley series. This course is part of the major program at Haverford and "consists of a mixture of fundamental physics and applications drawn primarily from geophysics and atmospheric physics." Appendix 2 shows his listing of the applications investigated.

In Prof. Gollub's words, "Its primary goal is to teach good physics while promoting an interest in and understanding of the environment. Many of the applications require simultaneous use of various parts of physics. For example, black body radiation, atomic spectra, and thermal transport, etc., are all required for a treatment of the energy balance of the earth as a whole. Thus the discussion of geophysical applications can promote a kind of synthetic thinking that is often missing from the usual single subject courses."

I find myself personally in strong support of this kind of addition to the major curriculum. It has several simultaneous benefits. It returns the breadth of application that has been missing, it deals with immediate problems, and it can appeal to upper-class science majors other than physics majors. The mix of talents and interests in such a group should itself be educationally beneficial and stimulating.

The preparation of this kind of course is unusually demanding on an instructor's time and creativity, both of which are usually in short supply. I will discuss in a later part of my talk some of the resources which are available to an instructor who wants to design such a course. The most important resources, however, are the other physicists who are already working in this area. I hope the listing which the CCP will publish will help put the right people in contact. I further hope that the AAPT or the AIP Information Pool can continue the informal clearinghouse which we began.

Seminars

A second popular offering which combines physics and the environmental theme is the seminar. This is an obvious pedagogical vehicle for handling the disciplinary mix involved. A representative statement of goals and methods is presented by John Harte of Yale:

> The purpose of this seminar is to provide both science and non-science majors the experience of using science to aid in the understanding of complex environmental issues. Topics in the physical sciences will be developed with the emphasis on applications and model building. For example, the subject of energy conservation will be treated by analyzing how the earth, a city, a forest and a power plant conserve energy. In order to confront the realities of actual environmental problems, a case study approach will be adopted. Individual and group projects will form a substantial part of this seminar. Stress will be placed on the interdisciplinary aspects of environmental issues.

Seminars have a high probability of success, given the student involvement and low student-faculty ratio. They would seem to me, however, best thought of as a capstone to more formal coursework causing a student to synthesize and apply material and methods learned in other courses. However, I believe that the environment theme has something important to offer in the large elementary level courses that are more the norm in our institutions of higher learning.

Introductory-Level Courses

The introductory-level courses fall into two main categories and the difference between them is, I believe, quite important.

In one kind of course the central goal is to acquaint the student with current environmental problems, and the syllabus lists topics such as air pollution, the city, DDT, the Santa Barbara oil spill, or human reproduction and population problems, thermonuclear warfare and ABM systems, wastes and pollution, etc. These topics are often treated on a case study basis and the students are expected to do similar though perhaps less ambitious case studies themselves. The approach of such courses is well exemplified by the excellent collection of case study essays in The Patient Earth by John Harte and Robert Socolow, Holt, Reinhart and Winston. Paper C-4 by Prof. Wolfe provided us an example this morning.

The role of physics in such a course is most often incidental, occasionally the problems presented are physical, more often the problems are the usual ecological mix of all the natural and social sciences. A physicist as instructor brings to bear little of his direct professional expertise; more often his leadership comes from his easier access to and familiarity with the literature, his practice with evaluating and analyzing complex problems and whatever carryover of objectivity he manages to maintain.

Because of the wide sweep of such courses the students themselves cannot be brought to the point of making independent analysis; the emphasis is on the results of analysis rather than on the techniques. The goals seem to be to make students aware of threats to the environment, to show students the complexity of the problems, to make them aware of one or sometimes more suggestions for solutions, to show them examples of the politically active expert at work, to lead them to the varied literature on these subjects, etc. An implicit goal seems to be the demonstration that scientists care about these societal problems.

I do think I am being entirely unfair to compare this kind of course to a literature course in which one reads and discusses certain literary classics, is given examples of criticism and deeper analysis, but the goal is to understand the works themselves rather than to develop a broad technique of criticism and analysis. Literature courses are useful and popular in undergraduate education. Environmental case study courses can and do make a similarily strong case for existence. I do not mean to question the academic propriety of this kind of course. I do wish to come back to them after I have discussed another type of introductory course and raise some questions about goals and priorities.

The second general category of introductory course has goals which seem to me to be more closely related to the traditional goals of the physicist-educator. The primary aim seems to be to present physics or at least physical science in action, the goal of developing an understanding of the environment with its problems is clearly secondary. Most of these courses are organized around themes that have definite physical science content. Among the more popular topics are:

1. Power and Energy
   - The Electric Power Crisis -
   - Nuclear Energy -
2. Transportation
3. Physics and Chemistry of Pollution
4. The Atmosphere
5. Radiation Hazards.

It is easy enough to see from these titles the kind of physics that can be taught under the various rubrics; the first and second law under Energy, as well as energy conversion, efficiency, etc.; laws of motion, work, power and energy under Transportation; some atomic and molecular physics under Pollution; gas laws and some dynamics (including Coriolis force) under Atmosphere; some nuclear physics under Radiation. To give an example of the perhaps surprising depth of the physics, I will later on give an expanded topic outline of my one-semester course on "Energy and the Environment."

The subject headings above emphasize the concepts and laws -- the content of physics. But there are courses in this same category which emphasize the "processes" of physics, a distinction I have found useful to make. These courses are organized under headings such as the following:

The Systems Approach
Model Building
Feedback
Probability and Statistics
Numerical Estimation.

As an example of a course emphasizing these process goals I have a course description of "Physical Models in Environmental Analysis" taught by Prof. Barry Walton at the University of California-Santa Cruz. In this course the students are given a presentation of ideas such as systems analysis, model building, feedback and then, after the necessary fundamental physics, apply this combination to examples--feedback for instance in amplifiers and environmental problems, probability and statistics in game theory and in the ABM problem. The students use a systems analysis approach in the Project ICARUS approach. (Project ICARUS, as I understand it, is a hypothetical problem posed to some MIT students in which they were, from orbit data, to determine whether planetoid Icarus would hit the earth and then figure out how to destroy it before it accomplished this.) Model building would be applied, for instance, to mass transport systems. Not only would these examples stress the physical constraints but such ideas as "cost effectiveness" and "trade-off."

I feel strongly that one should deliberately set about to achieve goals of both types. The priority for undergraduate physics education is shifting and must continue to shift toward service and responsibility to the entire undergraduate student body. In the words chosen by the conferees at the CCP sponsored Conference on Priorities for Undergraduate Physics Education, "Departments should redesign their educational programs so as to reach a substantial and representative fraction of their college or university community."

We are now faced with a double challenge, to design courses which implement as achievable goals the reasons behind distribution requirements and which are, at the same time, attractive enough to attract and hold students without the backup threat of these distribution requirements.

If the reasons behind our attempt to expose students to physical science are examined, we find them couched in the language of "process" rather than content, we want students to understand how physics operates, its strengths and limitations, etc.; we do not want to make physicists of them. To accomplish these purposes we have in the past used a less sophisticated introductory course. At the present, there is much imaginative redesign of these courses underway, and one sees such course titles as "Physics for Poets" or "Physics and Antiphysics" or "Physics and Man." It is however the goals which are important and course design must be guided by them.

To pass from the general to the concrete, let me report on a specific example, the course "Energy and the Environment" which I am working to develop.

The content goals are made most easily visible in the course syllabus.

I. Fundamentals of Energy

- A. Survey of role of energy
- B. Usefulness of energy concept
- C. Kinetic and potential energy — 3 weeks
- D. Heat as a form of energy
- E. Energy conservation

II. Heat Engines and the Second Law

- A. How heat engines work
- B. Carnot engine, efficiency — 3 weeks
- C. Reversibility and irreversibility
- D. The second law and entropy

III. Conversion and Consumption of Energy

- A. Forms
  1. Primary: Solar, gravitational, nuclear chemical, geothermal
  2. Intermediate: Thermal, mechanical, electrical, chemical, radiant — 4 weeks
- B. Methods of conversion
- C. Patterns of consumption-the importance of electrical energy

IV. Environmental Effects

- A. Pollution — 2 weeks
- B. Resource depletion and misuse

V. Energy Resources and New Forms

A. Estimation of fossil fuel resources
B. Advantages and disadvantages of nuclear energy — 2 weeks
C. The promise of fusion
D. Solar energy
E. Other forms, including geothermal

There are several content goals implicit here. I am teaching some laws and concepts; energy, entropy, heat, temperature, work, power, etc. The students must understand energy conversion, energy units, etc. I emphasize the complex nature of the problems of energy, the interlocking of science and society. I also emphasize some of the skills of physics -- reading graphs, setting up and solving numerical problems, collecting and analyzing data.

The process goals are difficult to verbalize in behavioral terms. I am trying, largely through the laboratory and student projects, to cause the students to gain some understanding of the nature of the scientific enterprise. I want the student to have followed reasing based on indirect observations, have worked through, in certain instances, the steps of model building, prediction, testing, analysis, and refinement that form the "scientific approach," and particularly to see both the power and limitations of these methods and of the human scientists which practice them.

I also hope to develop in the students some competence with some of the intellectual strategies and some appreciation for the attitudes of science, some competence with abstraction, model building, estimation, problem construction and solution, etc., and some appreciation for the questioning attitude, for the reliance on experiment, etc. Above all we want to decrease his or her awe of science.

What has become clearer as I have worked through this course once, and prepare for a second semester, is that my goals and the students' goals are apt to be different. Most of the students come into this course because they want to find out something about the energy crisis and the related environmental problems. If I can help them attain their goals and at the same time achieve a reasonable percentage of mine, I will consider the course a success.

Evaluation

Success is so often a subjective term. I want to measure it. To determine the degree to which I satisfy the students' goals I am content to settle for a student questionnaire. If they are satisfied, I am; if they are not, I want to know what they feel went wrong.

My evaluation of their achievement of my goals takes several forms. I test for achievement of the content goals by assigned problems and by in-class testing and discussion. I look for their ability to utilize the concepts and laws in the student projects. The process goals are of course more difficult to test for. I can build toward their achievement in the laboratory by putting them through a sequence of experiments in which they are required to become more and more independent. I can also judge from the way they handle their projects whether they are developing the attitudes I am aiming toward. I look forward, with a larger group of students, to collaboration with more experienced educational research experts in our school of education in the design of better evaluatory instruments for these process goals.

I have emphasized this second category of environmental courses because I believe that it can fill an important place in our departmental offerings. It is a first step outward from the core of the discipline toward the great majority of the students. In teaching it a physicist can deal from his professional strength; he does not need to shape his offerings to a list of environmental problems, but rather shapes that list to physics.

Resources

It is a step outside, however, and calls for a different set of resources than those commonly available in his library. I will conclude my presentation by mentioning some sources in which some of the necessary information is easily available.

As I have mentioned, the results of the CCP survey with individual course descriptions will be published with the final Priorities Report -- I hope by sometime this spring.

A second publication which will be of major assistance will be an AAPT Resource Letter on "Energy, Resources, Production, and Environmental Effects," which Bob Romer at Amherst is completing. It is a thorough job and will be of great value.

The Environmental Workbooks of the Scientists Institute for Public Information are an already available source. These workbooks combine a subject matter review and a bibliography. A list of the

eight titles follows:

Air Pollution
Environmental Cost of Electric Power
Environmental Education 1970
Environmental Effects of Weapons Technology
Hunger
Nuclear Explosives in Peacetime
Pesticides
Water Pollution.

Another very useful bibliography is "Science for Society," prepared by John Moore for the Commission on Science Education of the AAAS. It is available at a nominal cost from the AAAS.

Also, Robert W. Dunenberger of San Fernando Valley State College has published "Environment and Man, A Bibliography," available from National Press Book, 850 Hauser Way, Palo Alto, California.

The Committee on Environmental Alterations of the American Association for the Advancement of Science and the Scientists' Institute for Public Information are in the process of publishing their Electric Power Task Force Report. It will be available from either AAAS or SIPI.

ENVIRONMENTAL BIBLIOGRAPHIES

1. "Energy: Resources, Production and Environmental Effects"
   AAPT Resource Letter
   Robert Romer
   Amherst College

2. "Environmental Workbooks"
   Scientists' Institute for Public Information
   30 East 68th Street
   New York, N.Y. 10021

3. "Science for Society: A Bibliography"

   Commission on Science Education
   American Association for the Advancement of Science
   1515 Massachusetts Avenue, N.W.
   Washington, D.C. 20005

4. "Environment for Man, A Bibliography"
   A National Press Book by R. W. Dunenberger
   850 Hansen Way
   Palo Alto, California 94304

Finally I would like to mention a project which grew out of discussions within the new AAPT Council on Physics in Education. I have proposed to undertake, with the help of an interdisciplinary steering committee and the support of the other college level science education groups, the production of Environmental Resource Packets. I would see these Resource Packets as dealing with topics such as Transportation, Nuclear Energy, Air Pollution, Population, Pesticides, etc. They would consist of a review paper, a carefully selected and thoroughly reviewed bibliography, and perhaps some simple visual aids. They would be directed at college science faculty and have the aim of providing complete preparation on the selected subjects, and allow faculty either to incorporate the material into courses or to serve as an information resource person to the local community. If this project is funded and if these packets are accepted as useful by the college science community, we will seek to establish them with some kind of subscription service to keep them updated.

I will admit from experience that it is a difficult task to move away from established textbooks and design courses of the type I have been describing. It takes a fresh analysis of goals and methods, new kinds of evaluatory techniques, and new materials. There are, however, many of us working at this and new converts join every day. The CCP has tried to foster supportive communication between this band of innovators. I hope some other organization will take up this task. Above all, though, I hope that the work will continue. The environmental theme should remain one of immediate concern for some time. One has only to step outside to be reminded of its importance. Physics can contribute much to its understanding. But the environmental theme, properly used, can also make great contributions to physics. Through it we can reach and teach those students who in short years will themselves determine the environment in which physics will prosper or fail.

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APPENDIX 1

Ross, Michigan

Societal and Environmental Physics Outline

I. Introduction and Survey of World Problems
(3 weeks)

- Population
- Resources (energy, entropy)
- Armaments

II. Statistics and Earthquakes
(5 weeks)

- Earthquakes
- Probability and simple distributions
- Random samples, mean, variance
- Statistical inference, especially binomial distribution
- Curve fitting
- Dependence on two or more variables
- Application to earthquakes and nuclear explosions

Project 1:

Statistical Study of a Possible Connection between Nuclear Weapons Tests and Earthquakes

III. A Device for Measuring Pollutants in Automobile Exhaust
(2 weeks)

- Auto pollution, its effects; social indicators
- Infrared radiation
- An infrared pollution measuring device

Project 2:

Technical Evaluation of the Safeguard ABM System

IV. Analysis of the 'Safeguard' Antiballistic Missile System
(3 weeks)

APPENDIX 2

Gollub, Haverford College

Physics of the Earth and its Atmosphere

I. Statistical and Thermal Phenomena

A. Transport theory

1. The earth's internal heat
2. Thermal transport in the atmosphere
3. Dispersal of pollutants from a local source

B. Thermodynamics

1. Adiabatic processes in the atmosphere
2. Entropy changes associated with atmospheric processes
3. Entropy of mixing and the resource problem

C. Black body radiation

1. The earth's energy balance
2. The effects of particulates, carbon dioxide, and human energy production on climate

II. Periodic Mechanical Phenomena

A. Oscillations and Resonance

1. Seiches
2. Free oscillations of the earth
3. Atmospheric tides

B. Acoustic Waves

1. Seismic waves in the earth
2. Normal modes of sound in a room
3. Noise

C. Ocean waves

III. Electromagnetic Phenomena

A. Electricity in the atmosphere: thunderclouds, charge separation, and lightning

B. The earth's magnetic field

1. The dynamo theory of geomagnetism
2. History of the earth's magnetic field from magnetized rocks

C. Electromagnetic waves

1. The dielectric constant of the atmosphere
2. Reflection of electromagnetic waves by the ionsphere
3. Light scattering in the atmosphere.