Case Studies in Science— A Novel Method of Science Education

Clyde Freeman Herreid

The following article by Clyde Freeman Herreid, Distinguished Teaching Professor at SUNY, Buffalo, is the first in a series of articles to be published in JCST on the use of case studies in teaching science. The editor and staff of the Journal hope that this article will stimulate the contribution for publication of other discussions on case methods in science teaching.

Schools around the nation are seeking curriculum reform and classroom innovations to aid in rectifying the deficiency in scientific literacy. The case-study method is one innovation that holds exceptional promise.

Science education in the United States has been faulted by politicians, laymen and scientists. Comparisons among countries using standardized mathematics and science tests repeatedly shows the United States trailing many European and Asian nations. J. Miller's *National Surveys of American Scientific Literacy* (1983) reveal large percentages of people who believe in astrology, occult experiences, extraterrestrial landings on earth, and creationism along with a woeful misunderstanding of basic science concepts.

Our deficiencies in science have been cited as a harbinger of the demise of the United States' preeminence in technology. Its long-term economic leadership has been questioned. Educators have been quick to point out that science education is not user-friendly, disproportionately turning off large numbers of women and minorities.

How to correct the many perceived ills of our science education has occupied the attention of scientific societies including the National Academy of Sciences and the American Association for the Advancement of Science *(Project 2061: Science for All Americans!.)* Sheila Tobias says in her book *Revitalizing Undergraduate Science* (1992), that some 300 reports on the problems of American science and mathematics have appeared since 1983, yet with notable exceptions "it is difficult to show that these reports have had much impact." Schools around the nation are seeking curriculum reform and classroom innovations to aid in rectifying the deficiency in scientific literacy.

One innovation that holds exceptional promise—yet has had little trial among science teachers—is the case study method.

Case Studies as a Teaching Technique

Case studies have rarely been used in undergraduate science teaching except as occasional stories told by an instructor, perhaps as historical footnotes, to general lectures. James B. Conant of Harvard was apparently the first science educator to try and organize an entire course around this mode of teaching (Conant 1949). However, unlike the current practice in business and most other fields which present cases within a framework of discussion or Socratic dialogue, Conant presented cases entirely in a lecture format. Conant's model did not survive him and other attempts to use the method are not widely known.

In contrast, business and law schools have had a long tradition of using real or simulated stories known as cases to teach students about their field. Harvard University has been the leader in developing cases in these subjects (Christensen 1986), and has produced faculty who have carried their enthusiasm for the method to other institutions. Valuable case books in the field have been written about the pedagogy (J. Erskine *et al.* 1981). Other disciplines such as medicine, psychology, and teacher' s education have used the method to capture the imagination of students. The recent monograph *Using Cases to Improve College Teaching* (Hutchings 1993) is the newest effort in the field of teaching.

In these disciplines, cases are typically written as dilemmas which give a personal history of individual, institution or business faced with a problem that must be solved. Background information, charts, graphs, tables may be integrated into the tale or appended. The teacher's goal is to help the students work through the facts and analysis of the problem and then consider possible solutions and consequences of their actions.

For the past four years, we at the State University of New York at Buffalo have used case studies in three types of situations:

- As the core material of a general-education course, Scientific Inquiry.
- As part of two general education "Great Discoveries" courses where three paradigms are discussed in the form of cases in the classical sense of a historical story as envisioned by Conant.
- As an occasional case used in the laboratories and lecture of a large biology course.

We draw several conclusions from these experiences.

(1) Like case teachers in business, medicine, and law before us, we note that the case method involves learning by doing, the development of analytical and decision-making skills, the internalization of learning, learning how to grapple with messy real-life problems, the development of skills in oral communications, and often team work. "It's a rehearsal for life."

(2) Cases have strong appeal for many students who are turned off by traditional science courses oriented around a lecture format with a concentration on facts and content rather than the development of higher-order thinking skills. In a current course of nonscience majors using cases, we have 95 percent attendance while normal lecture courses have 50-65 percent attendance.

(3) Faculty must be shown how to write and to teach from cases, especially if discussion methods are used. These are techniques not common in the science classroom.

(4) A method of dissemination must be established so that teachers across the country can have access to the new material.

(5) The case method of presentation is extraordinarily flexible as a teaching tool, as I hope to illustrate with a few examples.

Robert Merry (1954) has written that the case process is inductive rather than deductive. He adds "The focus is on students learning through their joint, cooperative effort, rather than on the teacher conveying his/her views to students". Charles Gragg (1953) wrote a captivating article entitled "Because Wisdom Can't be Told", in which he stressed that the purpose of case teaching is to develop analytical and decision-making skills. Erskine *et al.* (1981) noted that students "are developing in the classroom, a whole set of skills of speaking, debating and resolving issues. They are also gaining a sense of confidence in themselves and relating to their peers." I would add that the use of case studies in science should encourage students to critically appraise stories about science they hear through the media, to have a more positive attitude about science, to understand the process of science and its limitations, and to be able to ask more critical questions during public policy debates.

In short, the goal in most of our case-method teaching is not so much to teach the content of science (although that does clearly happen) but to teach how the process of science works and to develop higher-order skills of learning. Looking at Bloom's (1956) taxonomy of cognitive learning, we focus less on "knowledge" than on comprehension, application, analysis, synthesis, and evaluation. Cases seem ideally suited to illustrate the relevance of science in society. Cases are equally

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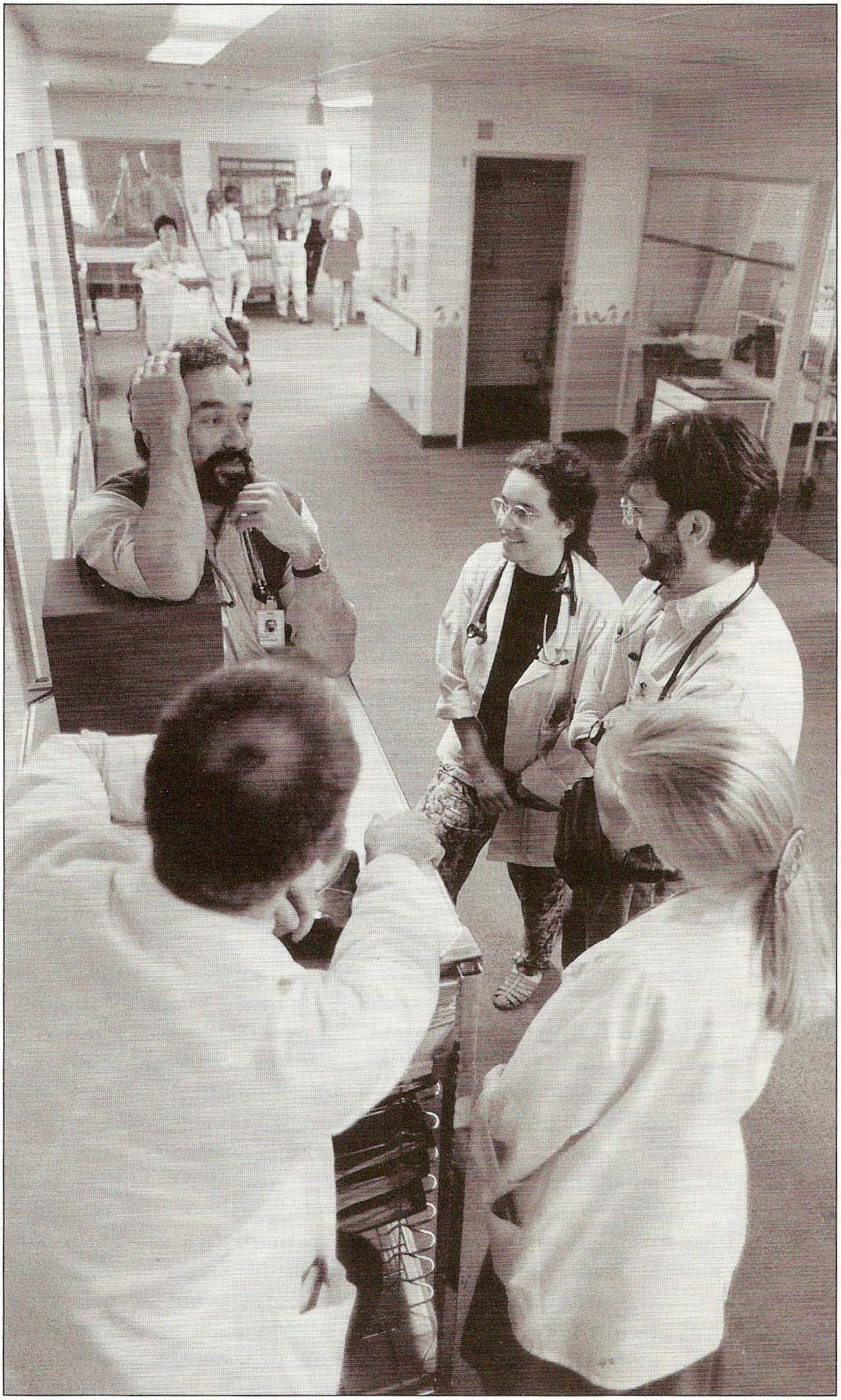
suited to the collaborative/cooperative learning format in small groups but can easily be used in large discussion classes, as exemplified in law and business schools. They can even be adapted for megaclasses of students.

How to Write a Case

There are two basic questions that face anyone interested in using the case method. The first is, how am I going to write the case? The second is, how am I going to teach the case? The two questions are clearly related, for the case often will be written differently for different teaching formats.

How much work is required in writing the case varies enormously depending upon the materials you decide to provide the students. One of my colleagues, Michael Hudecki, uses a single 100-word paragraph from *The New York Times* as the basis for an entire class period. As class begins, He gives the students this brief announcement of an experiment in memory loss in mice. He asks them to write concise responses to the following questions: What is the problem being investigated? What are the details of the experimental method apparently used? What are the pertinent results? What specific conclusion can you draw from the study? Then, with gentle and probing questioning, he is able to draw out a miraculous number of vital points about the scientific process. Before the students realize it, they are creating control groups, hiring research personnel, spending taxpayer's money, and curing Alzheimer's disease. At the end of the class period, the blackboard is a blizzard of speculations, experiments, and conclusions, and virtually all of the students are eager to read the original research article published in the *Proceedings of the National Academy of Science* to see if their suppositions are correct.

At the other extreme, cases may take elaborate preparation requiring dozens of pages of text and extensive research.



MCMASTER UNIVERSITY PUBLIC RELATIONS, HAMILTON, ONT.

One case-study method, "Problem-based Learning," is faculty intensive, using one tutor for every four or five students. The group, such as these Health Sciences students pictured here at Canada's McMaster University Faculty of Health Sciences, stays together for the entire term, working through a series of cases.

Business cases may require over a year of information gathering and interviews along with thousands of dollars of investment to develop a case that may extend over several class sessions.

Mount Holyoke College has put such an investment into an interdisciplinary course called "Case Studies in Quantitative Reasoning" (Pollatsek and Schwartz 1990). Designed and taught by members of at least eight departments, it uses only three cases in a semester to develop reasoning and evaluation skills. The first case is on Salem Village witchcraft and involves writing a paper "formulating and discussing a hypothesis about the relationship between wealth and power as reflected in the historical records for Salem Village during the 17th century." The second case deals with measurement and prediction: SAT scores and GPA. The final case deals with Rates of Change: Modeling Population and Resources. Obviously these cases have required major investments of preparation time, finances and class time. As with any case study approach, Mount Holyoke faculty have carefully laid out a series of detailed objectives which each of these cases illustrates. *These* objectives are attained through one lecture, two discussions, and a computer lab each week.

■ Pre-existing Materials—Case materials can be found prepackaged almost anywhere: in newspapers, magazines, novels, cartoons, videos, and television dramas. The motion picture "Jurassic Park", based on Michael Crichton's novel, is an ideal story to consider questions about scientific responsibility as well as DNA technology. Criminal trials reported on in the press may be used to highlight the recent use of DNA fingerprinting to identify suspects. The play "Inherit the Wind" is an excellent vehicle to discuss evolution and its place in the public school system. Advertisements for health food, vitamins, and pharmaceutical agents are prime materials for cases. Gary Larson's cartoons from the *Far Side* are a rich source of biological case material, as are tabloid papers with their outrageous stories. These need not be dressed up with extensive writing to work as case material.

As in law, business, and medicine, the case method involves learning by doing; the development of analytical and decision-making skills; the internalization of learning; learning how to grapple with messy, real-life problems; the development of skills in oral communication; and often team work. "It's a rehearsal for life."

For the very adventuresome, there are detailed medical cases published each week in the *New England Journal of Medicine.* Many teachers may find these intimidating but the cases need not be used intact. They can be edited to suit the occasion. In fact, some of the most interesting cases can be developed by taking one or two graphs and tables from any scientific article and asking the students to interpret the graphs or plot the data, postulate the methods, and speculate on the conclusions of the author.

Another technique is to simply collect a series of articles focused around a single topic. These articles are put on library reserve, or copied with permission from the journal involved and then given to the students. If accompanied by a short series of questions to guide their reading, an outstanding case can be developed. For example, in 1988 there were several articles and letters to the editor published in the journal *Nature* about the spectacular claims from the laboratory of the French immunologist, Jacques Benveniste (Devenas *et al.* 1988). The paper theorized that water may hold the "memory" of a substance that it once contained. This caused an uproar in the scientific community. Claims and counterclaims were flung across the Atlantic *with a* magician being part of a "fraud squad" brought in to help settle the dispute. While this is hardly a flattering moment for science, the letters and articles are especially enlightening to focus upon questions of data interpretation, suitable experimental design, double blinds, and the role of editors in the publication process.

In summary, preexisting materials are cheap and easy to find. They come from familiar sources and are recognizable as authentic parts of the student's world. There is an immediacy in their use; one can see an article in the press in the evening and be using it in the classroom the next day.

■ Writing Cases—Many cases are best developed from scratch. This is the process used for most business cases and although it requires considerable time, it has the advantage that only essential material is included in the writing. The case may be customized exactly to meet the teacher's goals. Reynolds (1980) has classified cases into three basic types:

(1) Decision or dilemma cases present problems or decisions that

need to be made by a central character in the drama. The case usually consists of a short *introductory* paragraph setting up the problem to be considered and may introduce the decision-maker at the moment of crisis. A *background* section fills in the historical information necessary to understand the situation. A *narrative* section then presents the recent developments leading up to the crisis that our protagonist faces. *Exhibits* (appendices) follow including tables, graphs, letters, or documents that help lay the foundation for a possible solution to the problem. Examples might include a woman who has been disfigured in an auto accident trying to decide about having a breast implant, or an FDA official faced with a decision of releasing a controversial AIDs remedy with serious side effects, or President Clinton trying to decide what to do about the logging industry and spotted owl controversy.

The University of Minnesota has published a book entitled *Decision Cases for Agriculture* (Stanford *et al.* 1992) which has examples of how the method might be applied in that field. These cases follow the business school format; they are multi-page documents based on real cases and with extensive data. Another approach is used by David Newton (1992) in *Science and Social Issues,* which consists of brief dilemma cases obviously contrived for students yet based on important realistic problems.

(2) Appraisal cases ("Issue Cases") are used to teach students the skills of analysis. The material is focused around answering questions like "What is going on here?" It frequently lacks a central character in the drama and generally stops short of demanding that the students make a decision. Examples would be a description of the Valdez oil spill, or a collection of papers and data showing the possible effects of vitamin C on the common cold, or a selection of articles arguing whether HIV virus is the causative agent of AIDs. Ricki Lewis (1994) has put together a *Case Workbook in Human Genetics* which deals with issue cases. While obviously a student exercise book, it gains in credibility because it deals with real people.

(3) Case Histories are largely finished stories and are generally less exciting than decision or appraisal cases. They can serve as illustrative models of science in action and they provide plenty of opportunities for Monday-morning quarterbacking. Science is replete with cases of this type: for example The Copernican revolution, cold fusion, or the Tuskeegee syphilis study where several hundred black syphilis patients were studied for decades without modern medical treatment being provided.

How to Teach a Case

Eighty years of using the case method of teaching at Harvard and other institutions has led to dozens of articles and books on the topic. Virtually all of these publications center their attention on the discussion mode of teaching cases. This is too limited a view of the method and I offer a few alternatives that are suitable to many scientific cases. However, in almost all methods there is a common approach. The instructor must have his objectives clearly in mind, must structure the presentation to develop the analytical skills of the students, and must be sure that student participation is maximized.

■ Discussion Format—The discussion technique is the one classically used by business and law schools to deal with cases. Students are usually presented with decision or appraisal cases. The instructor's job is to identify, with the student's help, the various issues and problems, possible solutions, and consequences of action. On the surface of it, the method is simple: the instructor asks probing questions and the students analyze the problem depicted in the story with clarity and brilliance.

Case-discussion instructors vary enormously in their classroom manner. On the one hand, you have the strong intimidating approach used by Professor Kingsley in the movie and television series "The Paper Chase." This strong directive questioning approach is often called the Socratic Method. The "all-knowing" instructor (acting as inquisitor, judge, and jury) tries to extract wisdom from his student victim. In its worst form, the questioning can be a version of "I've got a secret, and you have to guess it." In its best form, it can bring about an intellectual awakening as insights emerge from a complex case.

On the other hand, you can have almost nondirective class discussion. The instructor can practically stay on the sidelines while the students take over the analysis. The instructor may start the discussion with a minimum of fuss saying, "Well, what do you think about the case?" From that moment on, the instructor may merely act as a facilitator or "traffic cop," being sure that some semblance of order is kept and students get to voice their views. Finally, the class may end without any resolution of the issue or summation. The virtues of this nondirective approach vs. the directive Socratic approach may be debated, but most practitioners of the discussion method prefer a middle ground. William Welty (1989), writing on the "Discussion" method in *Change* magazine, argues for such an approach with proper introduction, directive but not dominating questioning, good blackboard work to highlight the essential issues, and an appropriate summary.

Many experts argue that the best class size for discussion is perhaps 20 to 60 students. When class size is too small there is not enough diversity of opinion. When it is too large the chances that a given student can participate even once a semester becomes small. There is little incentive to prepare adequately.

■ Debate Format—Debates used to be common in the American educational system, and many an aspiring politician and lawyer got his start in debating clubs and societies. Few people have seen formal debates and have the Presidential Debates as their only frame of reference.

Debates are well suited for many types of cases where two diametrically opposed views are evident. Propositions such as the following are ideal for the debate format: "HIV virus is the causative agent of AIDS;" "Nuclear energy must be an essential part of our energy production system over the next 100 years;" "Abortion must be available for women."

A good format for the debate is to follow the procedure of moot court competition. Two teams of students each prepare written briefs on both sides of the issue and are prepared to argue either side. Just before the actual debate, they draw lots or flip a coin to see which side they must argue. The debate itself starts with the pro side presenting for five minutes. Then a member of the con side speaks five minutes. There is a five-minute rebuttal by a second speaker on the pro side, followed by five-minute rebuttal on the con side. This is then followed by three-minute summaries by each side. In a classroom setting where some members of the class are not participating in this particular debate, it is valuable to permit questions from the audience and to ask them to evaluate the content and presentation of the debate.

The team sizes can vary, with three individuals per side being logical. However, there can easily be larger numbers. These "extras" can be used in several ways. One possibility is to use the two or three extras to help prepare the teams for the debate, help write the briefs and be on hand to answer questions or to give rapid advice during the debate itself.

■ Public Hearing Format—Public hearings are part of many procedures in the United States. They are used by the Congress and by public agencies and regulatory bodies. They are an ideal format to allow a variety of people to speak and different views to be expressed. Their use in case studies has similar strengths and has the added virtue of mimicking real-world events.

Public hearings are structured so that a student panel, role-playing as a hearing board, listens to presentations by different student groups. Typically, the hearing board (for example, Environmental Protection Agency, Food & Drug Administration) establishes the rules of the hearing at the outset (for example time to speak, order of presenters, rules of conduct, regulations and criteria governing their decision-making). This is followed by individuals or groups role-playing particular positions. Members of the panel often ask follow-up questions of the presenters. After all of the presentations are completed, the panel makes it's decision or recommendation.

Teachers using this method may find that the Public Hearing approach works most effectively over more than one class period. This permits students the maximum chance-to see the entire procedure play out and the preparations to be extensive.

■ Trial Format—Trials have inherent fascination because of their tension and drama. In the Trial Format, there are two opposing sides each represented by an attorney, with witnesses and cross-examination. The case I will use to illustrate the method (The Case of the Northern Spotted Owl) could effectively be presented by any of the methods we have already mentioned but for pure drama, the trial method is hard to beat. Here is the way I ran this for an evolutionary biology class of 370 students. It serves as a reminder that not all case studies must be done in small classes and that a single case in an otherwise lecture course can serve as a wonderful stimulus for class interest.

The case is the conflict between environmentalists wishing to preserve the spotted owl and the lumber industry of the Pacific Northwest. Although these two sides of the issue can be framed in extreme terms, I believe it is best and more realistic to frame the argument with more subtlety. There are not just two positions in the debate nor are there just two solutions. Environmentalists cannot simply be dismissed as long-haired, dirty-fingernailed, boot-wearing, tree-worshipping nuts. Nor can the logging industry be characterized as slobbering capitalist pigs with no concerns except the almighty dollar. There are bright, concerned people on both sides of the question and there are more solutions than either clear-cutting the forest or destroying the logging industry. It is important that students understand this. As a consequence, in the trial below we have tried to use "witnesses" with different views. The 20-page case which we handed out to all students before the trial was written to represent different perspectives, as well. The case finishes with four different plans to deal with the problem.

In presenting this trial before a student audience, I used undergraduate teaching assistants who help in the laboratories of the course. I used two assertive, confident individuals as attorneys and team leaders. Together they and the other teaching assistants worked out the roles, the basic script, and format of the presentation. We decided not to treat this in a spontaneous, unrehearsed fashion, because too many important points might not get developed. Instead, we developed a script where each "witness" knew the essential points they must develop in their presentation and the points to mention during cross examination.

The format of the trial was as follows. After a brief introduction by myself, the attorneys for the two sides took over. First the logging interests were presented by an attorney and three witnesses. Each witness was allowed three minutes followed by two minute responses during cross-examination by the opposing attorney. The first witness for the logging industry was a "scientist" who described the owl and the basic problem. They presented the possibility that the owl might become extinct regardless of the cessation of logging. The second witness was a "member of the U.S. Forest Service," who supported multiple uses of government land. The last witness was a "logger" who not only presented their personal plight, but the economic problems which would occur if logging ceased.

The opposing view for the owl and environmental concerns were first represented by a "member of the Fish and Wildlife Service" who was seeking some sort of compromise, but was most assuredly against clear-cutting. The second witness was a "representative of the local Audubon Club" who was concerned about the cultural and aesthetic issues in the case—the preservation of our basic heritage. The final witness was a "representative of the Sierra Club," who strongly advocated a no-touch policy, arguing with facts and figures that the logging industry will soon be out of business in the Pacific Northwest regardless of whether they cut the forest or not.

The trial proceeded with each side alternating their witnesses and cross-examination. Following the last witness, the attorneys for each side summed up their positions in three minutes, finishing with the logger's position.

It was essential that the student audience not see this case as merely entertainment. There were two methods to get student involvement. *First,* prior to the trial, we asked that students work in teams to develop two position papers, one favoring the extreme environmental stand and the other the extreme logging interest stand. These were to be short (two-page) outlines listing the key arguments on each side. These papers were turned in at the time of the trial. *Second,* at the end of the trial, all students were asked to write two-minute reaction papers. They were to respond to two questions: Which plan did they prefer to resolve the issue and why. These papers were then collected as the students left class.

In almost all methods of case-study teaching there is a common approach. The instructor must have his/her objectives clearly in mind, must structure the presentation to develop the analytical skills of the students, and must be sure that student participation is maximized.

■ Problem-based Learning Format—Medical schools have used the case method of instruction for years. Seasoned physicians have always posed problems to interns, residents and students as they made their rounds. Not until McMaster University of Canada developed the method for its entire curriculum was the full potential of the approach realized. Since then, the method has spread to other medical schools that have been frustrated with the fact-crammed lectures in traditional curricula. A review of the method is provided by Barrows (1986) and an unpublished review by Koschmann *et al.*

Problem-based Learning is faculty-intensive, for it uses one tutor for every four or five students. They stay together for the entire term, working through a series of cases. The cases are typically linked by some common area of study or progressive shift in complexity.

A typical case passes through several stages. In their first meeting, the instructor presents a short written account of the patient with some symptoms and background. The faculty and students together try to identify the points they think they understand and determine those terms, tests, procedures, symptoms, etc. for which they need more information. At the end of this meeting, students agree on how each will divide up the responsibilities to search for the needed information in the libraries.

In the second meeting, students discuss their findings and share opinions. Their search for the correct diagnosis narrows down. By the end of the class meeting, the students have determined what new information they need to uncover and go their separate ways to find it.

At the third meeting, students share their thoughts, data and understanding. They try to reach closure on the diagnosis and treatment. This is the last step in the process and generally students will not find out the "real" answer to the problem. The knowledge and understanding of the case comes from the search for answers not from "the answer" to a particular case. The power of this method is its interactive approach between thinking, discussion, and searching for more information. Consequently, it mimics the approach we usually use in real life.

■ Scientific Research Team Format—The essence of most scientific research is the case method. As scientists, we are constantly confronted by problems, questions, or dilemmas. We usually have a large background of information which we can use to "solve the problem." We are likely to use some version of the hypothetico-deductive method where we ask questions, make hypotheses, make predictions, test our prediction by observation and experiment as we collect data, compare the results with our predictions, and make evaluations and draw conclusions. Students usually have dim and faulty understanding of these steps, although they can usually recite some version of "The Scientific Method." Cases involving the above steps of science are particularly valuable for students. The more students take charge of the process, the more they are likely to appreciate what scientists actually do.

Depending upon the sophistication of the students and the facilities available, there are large numbers of real experiments that students may try. Typical lab experiments are poor substitutes for real science. So any attempt on the part of a teacher to have students question and gather data which are novel, is to be commended.

Here are two examples of student-research projects that generate interest and simulate certain types of science. The first involves the simple collecting of rain samples in different regions of the campus or city and measuring pH. The data collected over a semester will yield lots of tables and graphs for comparison with other regions of the country and lead to discussions of acid rain and its effect upon the ecosystem. Mundane though this project seems, it instills in students a great sense of many steps in the collection and analysis of data.

Although the case method cannot cure all of the ills in the teaching of science, it is nevertheless ideal for the development of higher-order reasoning skills, which every science teacher claims they strive to instill in their students.

The second example involves the testing of astrological claims. It is easy to have students devise tests of the likely validity of forecasts made by astrologers that I provide. Over several class periods, I ask them to work in small groups to come up with experimental protocols. They compare and criticize the protocols, collect preliminary data, then revise their experimental designs. Often at this stage they recognize the problem they will have in analyzing the data, and consequently simplify their approach. Again, they go out and collect more data, analyze it and write a full-blown research paper using the standard format of Introduction, Methods, Results, Discussion and References. The papers are group efforts and may differ significantly because the experimental designs may differ.

The papers will be exchanged between groups, and they will evaluate each other's efforts, using the normal peer-review process familiar to journal publication. They will criticize all sections, evaluating the design, adequacy of methods, presentation of results, and validity of the interpretation. Finally, they will accept, reject or accept the paper with revision. Whatever the commentary, all groups will revise their papers and submit them to the instructor for grading. At the end of this process, students feel they have an understanding of the process of science and the publication of papers.

■ Team-Learning Format—Michaelsen (1992) of the University of Oklahoma and his colleagues have devised a novel use of the case method which they call "Team Learning." It uses cooperative/collaborative learning strategies with small groups involved in a large classroom setting. The technique requires a radical overhaul of the typical classroom syllabus. It is not for the faint-of-heart, but it solves many problems which plague faculty trying to get students to prepare and attend classes, and it largely overcomes one of the major complaints against the use of the case method: that it doesn't cover enough facts and fundamental principles.

In brief, Team Learning involves setting up the class in permanent heterogeneous small groups of students (four to seven students per group). The syllabus of the course is typically subdivided into learning units, perhaps five to 10 in number. Each learning unit is approached the same way: (1) Individual reading assignments are given and read. These assignments cover the essential facts and principles of the unit. (2) A short (15-minute) multiple choice and true/false test covering the central points of the reading is given to individual students. (3) Then small groups of students immediately take the *same test* together. (4) Both individual and group tests are scored in the classroom (preferably using a portable testing scoring machine, for example Scantron). (5) The groups of students discuss their answers using textbooks and may make written appeal to the instructor. (6) The instructor clarifies points about the test and reading. Steps 2-6 generally occur in one class period. (7) Students now apply the facts and principles they have learned from the reading to a problem or case. This application phase occupies perhaps 80 percent of the course.

Here is an example drawn from my Scientific Inquiry course for nonscientists. The purpose of the course is to acquaint students with how scientists actually go about their work and how they interact with other scientists and society. Their first assignment is to read the National Academy of Sciences publication *On Being a Scientist* (1989), which covers the major principles of scientific conduct. The students are then tested on the material as individuals and as groups. Written appeals are received and discussed briefly. As part of the application process the groups are asked to generate a list of scientific commandments which apply to scientists and their code of behavior. They are asked to put their commandments in the form of "Thou shalt not..." or "Thou shalt..."

The groups are then asked to read a review of Pons and Fleishman's reported "discovery" of cold fusion, and are asked to compare and score the behavior of Pons and Fleishman with their group's list of commandments.

It is easy to see how the Team Learning approach can be used with most of the case study methods mentioned above. However, its particular strength is that it captures the power of small groups even in large classes of over 200 students.

PLUSES AND MINUSES OF THE CASE METHOD

The case method cannot solve all of the ills in the teaching of science. Even devotees admit that it is not the best method to deliver a plethora of facts, figures, and principles. However, the case method is ideal to develop higher-order reasoning skills which every science teacher claims they strive for. When cases are used occasionally within a course, they spice up the semester and show students how their esoteric learning impacts on the world and is dependent on political and social currents. However when used only occasionally, neither teachers nor students become comfortable with the method.

When cases become the predominant method of instruction this problem is avoided, but the question of information coverage becomes an issue. Traditionalists argue they can't cover the same amount of information using cases. This is true. Also, they warn that when social issues are involved in a science debate, it is always tempting for ill-prepared students to concentrate on the opinion issues. Naturally, teachers must be alert to keep the discussion on the science, evidence and analysis side. Faculty must develop teaching skills many do not now possess.

Cases are most easily used in general education courses dealing with science and society. There is little tradition to worry about or proprietary interest involved. However, the use of cases in science courses will probably be viewed with suspicion and skepticism. Faculty who have themselves survived and succeeded in traditional lecture courses and have years of yellowed lecture notes will be loathe to give way to what may seem as educational novelty. Yet this "novelty" has had a long history in the education of some of our finest lawyers, physicians, and business leaders. Cases can do equally well for scientists, especially if we wish them to care about how their work affects society. ❑

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