EXPLORING THE CONTEXT OF BIOMEDICAL RESEARCH THROUGH A PROBLEM-BASED COURSE FOR UNDERGRADUATE STUDENTS

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Students in an interdisciplinary program explored the manufacture of biomedical knowledge in a problem-based course. Because the class size was two to three times larger than the normal tutorial group, suitable modifications were made (formation of floating groups around defined learning tasks, formal presentations, written reports, and evaluations by students and tutor). A variety of problems and/or cases drawn from research papers, newspapers, biographies, or web pages permitted students to appreciate the complex interactions between ideals, individuals, institutions, and investments that comprise modern biomedical research.


Key words: active learning; problem-based learning; student-centered learning

Forty years ago Lord Snow’s Rede Lectures entitled “The Two Cultures” were published. He discussed what he felt was a serious problem, particularly in advanced Western society, namely, the emergence of two educated groups (scientists and literary intellectuals) that appeared incapable of communicating with each other. This description of the two cultures provoked considerable debate, and several years later he revisited the issue (17). He noted that

“In our society (that is, advanced Western society) we have lost even the pretence of a common culture. Persons educated with the greatest intensity we know can no longer communicate with each other on the plane of their major intellectual concern. This is serious for our creative, intellectual and, above all, our normal life. It leads us to interpret the past wrongly, to misjudge the present, and to deny our hopes of the future. It is making it difficult or impossible for us to take good action...” (Ref. 17, p. 60).

He emphasized that it was dangerous to have two cultures that either could not or did not communicate, particularly at a time “when science is determining much of our destiny, that is, whether we live or die. Scientists can give bad advice and decision-makers can’t know whether it is good or bad” (Ref. 17, p. 98). Thus science should be of great relevance not only to those who would become scientists but even more to those who will not.

The education that deprives non-science students of an awareness of what science is also short changes would-be scientists in a different way. It is ironic that science that epitomizes inquiry is often taught didactically so that students deal with science as a set of facts that have already become, whereas the process of becoming is virtually ignored.

This occurs even before students enter the portals of a University, as the comments of a high school student from Britain testify.

“I have found, surprisingly, that history requires more scientific thinking, methodology, and observation than
the traditional science subjects: physics, chemistry, and biology.

“In history, historical pieces of evidence are analyzed, interpreted, and compared with other evidence to form conclusions in a logical, scientific manner—like the results of a scientific experiment. We are told to consider evidence in terms of how it is limited and how different factors have changed its content and how this affects the validity of the conclusions made from evidence, as one would consider experimental variables in science. It encourages individual thought and promotes interest. . . .

“However, in science lessons we merely sit and receive dictation. We are not encouraged to understand, question, or find out for ourselves the facts that we are given. . . .

“Because science lessons do not encourage individual thought or interest beyond the syllabus, many students find it dull. . . “(9).

Comments similar to these have been made by students in the U.S. (17a) and thus reflect a more generalized attitude to science teaching.

One particular factor may lie in the excessive reliance on standard textbooks, at least in Introductory Science courses. Kuhn (6) noted that collections of “source readings” play a negligible role in scientific education so that other ways of looking at the problem are studiously ignored and controversies, arguments, and dissensions quietly erased. Science texts make little effort to describe the sorts of problems professionals are faced with or the variety of techniques available. On the contrary, the student is exposed to concrete problem solutions. This struck him as akin to “finger exercises” in musical training or language instruction, just the very fields in which an attempt is made to “produce with maximum rapidity strong ‘mental sets’. . . . Although scientific development is particularly productive of consequential novelties, scientific education remains a relatively dogmatic initiation into a preestablished problem-solving tradition that the student is neither invited nor equipped to evaluate.”

The result is that students graduate with little awareness of the ethos and/or the social context in which discovery occurs. The manufacture of knowledge is rarely examined.

I describe below an Inquiry course that seeks to provide students with an appreciation of the processes of scientific research and to examine critically the context of biomedical research in particular. The course (Discovery: The Context of Medical Research) forms part of the Arts and Sciences Program at McMaster University. I have used a modified problem-based format that was modeled on an earlier course that I taught in the same program (10). That course, The Curing Society, dealt with the larger issues of health and illness in our society. The new course focused more tightly on medical research.

The Arts and Sciences Program was created to provide students with a broad-based liberal education. The three major objectives were to provide students an opportunity to do substantial work in the disciplines of both arts and science, to further skills of writing, reasoning, and speaking, and to “foster the art of scholarly inquiry into issues of public concern” (http://www.mcmaster.ca/artsci/). This program has been extremely successful in attracting highly motivated students who enter the University with very high grades from high school. The core program includes courses in both the humanities (Western thought, Eastern studies, writing and logic, literature) as well as the sciences (biology, physics, calculus, and statistics). Inquiry courses have been set up to permit students to explore complex issues of public concern such as third world development, the environment, and the media. The course described below is taken by third- and fourth-year students.

THE COURSE OUTLINE

A brief description of the course is given to students when they enroll. Part of it reads as follows: Discovery is defined as the act, process, or an instance of gaining knowledge or ascertaining the existence of something previously unknown or unrecognized. In that sense discovering has formed part and parcel of human existence. However, the focus of this Inquiry course will be limited to a consideration of the “context”
(antecedents and consequences) of "scientific" discovery in the biomedical realm. Modern scientific research is an organized cooperative activity conducted in privileged spaces termed laboratories. The practices used as well as the information gathered are validated and legitimized by the scientific community before becoming public knowledge. This activity requires patrons who provide the resources required and who ultimately benefit or suffer from applications of the knowledge gathered. It must be emphasized that although research of this nature is international in scope, it is still colored by its origins as a creation of "Dead White European Males of the 16th and 17th centuries" (14).

The process of scientific discovery can be modeled as a "chain of discovery" or, better still, an expanding spiral (Fig 1). Prior knowledge or novel observations generate ideas that appear worthy of pursuit. Experimental scientists become actively engaged in gauging the "do-ability" of a project (2). This is a complex process that involves the marshaling of resources (skills, equipment, workers), the assessment of organizational support, and the framing of questions in a form likely to interest patrons. The pursuit takes the form of active interference and manipulation that provide new information. The novel information is presented to the scientific community, which validates its relevance and deems it worthy of entering the archives of the field. The archives provide a public record that can serve as the starting point for further exploration. The ideas and information generated may at any stage move out from the community of scientists and be available to society at large for exploitation and development.

One can take either a narrow or broad view of scientific discoveries. In the former case, attention is focused on the immediate antecedents and consequences, such as the status of knowledge at any particular juncture, that gave rise to the ideas that provided the impetus for the action taken (experiments). The methods used can be interpreted quite broadly to include not only the judgments that scientists make about reliability and interpretation of data but also the ways in which they work with each other and the strategies used to obtain information and justify it to the scientific community. These constitute the craft of science. The broad view focuses on the social forces that create the institutions that permit research of this kind to occur, the investments and the returns of such activity, and the mores and taboos of the communities involved. Scientific activity is not value free. Biases inherent in society influence the selection of questions deemed worthy of pursuit and, more importantly, those that are ignored. The methods used to obtain information as well as the justification procedures are colored by the values and training of the individuals involved (1, 4, 8, 20).

The above description is generally applicable to all the experimental sciences. The biomedical sciences do, however, have some special aspects. Medicine really has no unified body of scientific knowledge and thus uses as a conceptual base the more fundamental sciences of physics, chemistry, and biology. From these the biomedical sciences derive their principally explicatory character. The other aspect of medicine (the predictive, utilitarian) has no clearly defined scientific basis as yet. The resources that biomedical sciences command are more extensive and include not only the standard appurtenances of biology (animals, tissues, cells) but also patients. The laboratory in biomedicine can be expanded to include the clinic, the field, and the community. Although explanation and understanding remain paramount, biomedical research has a more applied flavor because there is an underlying expectation, assumption, or hope that the

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**FIG. 1.**
A scheme showing interactions between different elements that interact in the manufacture of scientific knowledge.
concepts that evolve and the discoveries made would be meaningful at sometime in a human context.

This outline is used to provoke a discussion with the students as to what they expect to get from the course and a list of topics they feel ought to be covered.

THE PROCESS

The course was run in a modified problem-based learning (PBL) format. The term “problem-based” is ambiguous and has been variously interpreted by different teachers and programs (7). Shorn of all rhetoric, it is a format that encourages active participation by the students by plunging them into a situation requiring them to define their own learning needs within broad goals set by the teachers. Situations, cases, and scenarios are used as springboards for learning. Although not strictly necessary, PBL has come to be practiced in a small group tutorial format. Here, six to eight students in a group use situations to raise issues, frame learning tasks, and individually seek out information that they share with each other in a subsequent session. In this particular case, I had larger enrollment (15–20 students). Given the larger class size (two to three times the norm for tutorial groups), I modified the system and took a more active role.

The several stages of a “typical” session are described below (see Fig. 2).

Brainstorming. A paper problem was distributed to the class. The entire class participated in raising the issues that arose from the problem presented. All ideas were entertained, however bizarre or profound. I played an active role by standing at the blackboard and acting as a scribe to ensure that issues raised were not missed.

Refining of issues into learning tasks. Once the students felt that a sufficient number of issues had been raised, they attempted to frame learning tasks (which served as objectives for subsequent sessions). This phase was difficult, because not all the issues raised lent themselves to framing of suitable learning tasks. Considerable negotiation occurred among the students with active participation on my part. The learning tasks that emerged were not sacrosanct and could be considerably modified by the next phase.

Formation of study groups. The learning tasks served as a focus for the formation of study groups, consisting of three to five students. Each student had to opt to form part of one study group. The students established a loose contract with the rest of the class to obtain and communicate the required information. At this stage further refinement occurred. Some learning tasks attracted a larger number of students, and some were left with no takers. When the students realized that no one was interested in the particular task as written, they either modified the task or decided to eliminate it or merge it with one of the others. It was important to preserve this aspect of
student autonomy. On occasion, I have been surprised that what appeared to be an interesting task found no takers, but to preserve the self-directed character of the course, I held my peace. This phase is considerably different from the conventional small group variant in which students remain within the same group and try to accomplish all learning tasks, albeit to varying degrees.

Preparation for presentations. The students met only once a week for a three-hour session, and they required time to meet and prepare for formal presentations, which usually occurred two weeks later. In the interim week, I tried to organize either guest lectures or visits to laboratories, etc., to discuss related issues that may have emerged.

Formal presentations. At a subsequent session, the groups presented their information to the rest of the class and provided an abstract. Whereas the presentations were evaluated by their peers, I graded the written reports. I distributed preset criteria. Students were told to give higher marks for clear statement of objectives, lucidity, logical sequencing of good examples, support of statements by use of good examples, enjoyability, interest of formats, and the abilities to provoke questions and give clear answers. Conversely, lower marks were to be given for dull, tedious presentations that were poorly organized, chaotic, or rambling and for which students were unable to spark interest and answer questions satisfactorily. The objectives of this phase were to provide students with an opportunity to present the information gathered clearly and cogently and for their peers to learn an aspect of the problem they had not researched personally and evaluate the presentations. It was the responsibility of each group to ensure that the workload was shared equitably because each member of the group was given the same mark. This aspect raised some difficulties, because students are comfortable giving comments but do not relish grading each other.

When all the presentations were completed, a new problem was taken up. This was the standard approach. Occasionally, I introduced some variation (see below).

A sample problem is shown in Fig. 3. This problem traced the sequence of events related to a significant discovery over a nine-month period. The problem raised a large number of issues that were finally resolved into five tasks that were taken up by independent groups.

The first group decided to explore the concept of being obese in North American society. They brought in video clips and images of beauty from fashion magazines and also discussed the emerging scientific notions of obesity and regulation of body mass. The second group looked carefully at the papers dealing with the obesity gene and tried to explain to the class, with simple clear diagrams, the rationale for the experiments. The third group looked critically at biotechnology and society and, in particular, at the consequences of academic-industrial relations and the potential for distorting the directions of scientific research. The fourth group focused on the publication process and looked at the steps by which submitted papers entered the public domain and the role of referees, editors, etc. The fifth group looked at the larger issue in relation to the dissemination of scientific information by the mass media.

Using the above format, students have discussed a wide variety of issues, ranging from the politics of developing contraceptives to the legitimization of knowledge (the controversies over the "memory of water"), the reward system in science, the politics behind the awarding of Nobel prizes, gender and racial discrimination in science, ethical issues related to animal and human experimentation, the design and conduct of epidemiological studies, space research, lead-screening programs, and regulatory mechanisms in relation to drugs and public health policies. The problems were derived from a variety of sources, ranging from articles in standard journals to biographical sketches, newspaper articles, and the web pages of particular agencies such as the National Aeronautics and Space Administration. Given the vast pool of source material, I have not needed to repeat the same problem or case, even where issues appeared to overlap. Thus issues related to the study of human fertility, contraceptive development, and population control were discussed using several different problems: an excerpt from a study by Hertig and Rock on blastocyst implantation, an excerpt from a feminist tract presenting divergent views from a standard history of the pill, and an article about the anti-fertility
vaccine published in the Proceedings of the National Academy of Sciences.

In a few instances, I adopted a slightly different approach. I presented students with a limited set of data and asked them to frame possible explanations for the observations made and suggest avenues for further exploration (see Fig. 4). A lively discussion ensued. After the students felt that they had argued enough with the limited information provided, I gave
A SOUTHERN TALE

In the middle of the 18th Century, Don Pedro Casal described a condition in the Spanish town of Aveida in the Asturias region. The local term was “mal de la rosa” from the peculiar red necklace-like rash around the exposed regions of the neck. The malady which later spread to several other countries (Northern Italy, Southern France, Romania, Russia, and Egypt) was associated with poverty and the production of corn. The disease had a progressive course and was characterized by dermatitis, diarrhea, dementia, and death (the 4Ds).

It was only in the early years of this century that the disease began to reach epidemic proportions in the North American continent, forcing authorities in the U.S. to take action. In 1914, Rupert Blue, the Surgeon General, assigned Joseph Goldberger, a little-known officer of the U.S. Public Health Service, to tackle “one of the knottiest and most urgent problems facing the Service” at that time. Dr. Goldberger, an immigrant physician trained at Bellevue Hospital Medical College, had by the age of 40 acquired extensive experience in investigating infectious diseases.

Given below is some of the information available to Dr. Goldberger from two institutions.

From the Georgia State Sanitarium for the treatment of insanity:

<table>
<thead>
<tr>
<th>Group</th>
<th>Total Number</th>
<th>Cases</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inmates</td>
<td>418</td>
<td>32</td>
<td>7.65</td>
</tr>
<tr>
<td>Employees</td>
<td>293</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: The number of cases refers to those that developed the condition after admission to the sanitarium.

From the Orphanage at Jackson, MS. On July 1, 1914, 68 of 211 orphans had the disease, giving a prevalence of 32%. A further categorization by age group yielded the following data:

<table>
<thead>
<tr>
<th>Age Group, yr</th>
<th>Total</th>
<th>Affected</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;6</td>
<td>25</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>6-12</td>
<td>120</td>
<td>65</td>
<td>54.2</td>
</tr>
<tr>
<td>&gt;12</td>
<td>66</td>
<td>1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

FIG. 4.
Another case used for discussion. Students were asked to frame possible explanations and suggest avenues for exploration.
The students have used a variety of methods to communicate the information gathered, ranging from formal presentations with overheads to debates, role playing, and creation of interactive situations. A group assigned to discussing peer review created a “Publishing Game.” They divided the class into multiple teams and asked each to organize the relative components (editors, publishers, reviewers, etc.) to create the most efficient system. This provoked furious discussion among the different teams, which ensured that never again would they regard a published paper casually! On another memorable occasion, students discussing the relative merits of red wine and the Mediterranean lifestyle in reducing the risks of ischemic heart disease presented their information in the form of a well-prepared Italian meal complete with nutritional data. I supplied the wine.

EVALUATION OF STUDENTS

Because this was an Inquiry course, it was important to permit students considerable leeway in defining their learning agendas. Nevertheless, I had clear expectations, and these could be separated into process- and content-related educational goals. Those related to process included the ability to generate issues from presented problems; frame learning tasks around the objectives; seek, appraise, synthesize, and present information; and evaluate performance on an on-going basis. The content objectives would be to obtain an overall appreciation of biomedical research from the two perspectives listed above.

In setting up evaluation procedures, I tried to make them consonant with the educational goals stated. I also wanted to use multiple evaluation procedures to permit evaluation of both individual and group activities.

Presentations. The presentations were evaluated by the entire class, and each student in the presenting group was given the same mark. Each student was asked to mark the presentations and give comments as well. I averaged the marks for each group and distributed a sheet collating the comments given.

Written summaries. Written summaries were handed in for each problem. These were brief descriptions of the material to be presented with careful statement of objectives, logical development of arguments, and selected references. These were graded by myself, and each student in the group was given the same mark.

A discussant’s report. In addition to the group summary, each student was expected to hand in a commentary on one of the other presentations. Specifically, I wanted the students to note what made them choose that presentation, the thoughts that it provoked, and what avenues for further exploration had been suggested. These reports were meant to be brief (1–2 pages) and prompt (handed in the week following the discussion of a presentation). In the first year, these reports were graded, but, because of persistent student complaints, in the following year I merely indicated whether the report was satisfactory or not.

A special essay. This was an opportunity for students to explore specific issues related to biomedical research in depth. They were expected to frame a suitable question, gather information, analyze it critically with adequate references, and write a clear, logical report. Each student was expected to submit a written essay of 3,000–5,000 words.

Student evaluation of the course has been generally favorable as judged from the numerical scores (see Table 1), and most of the comments were positive. On the whole, the PBL approach received favorable comments. Some selected examples include the following: “Extremely enjoyable and worthwhile to present problems and allow us to choose our own direction,” “really challenges students to develop different perspectives, to be capable of looking at a problem from many different angles—more importantly, to realize the existence of different angles,” and “profited greatly.” Another said, “I really liked the problem-based learning (which up until now I’d been very wary of); I loved the breadth of issues covered—a very unpredictable and enlightening course.” The negative comments were also very revealing and underscore the potential difficulties. One student noted, “I am not a huge fan of PBL. I find that it becomes too formulaic and predictable if used too often. However, the PBL format provides good scope to touch on a wide spectrum of issues related to biomedical research.” Other comments were that the process was “too cumbersome, the logistics of group work (were)
difficult to arrange,” and “the presentations quickly got dry” and that the approach used “also led to a discontinuous course in terms of content.”

I had instituted the discussant reports to determine whether students listened to each other and could reflect on what they heard. The written reports were often quite surprising. Some students who remained relatively quiet in the class wrote extremely thoughtful commentaries, which made me appreciate them all the more and see them with different eyes. This component received mixed ratings. Some felt that it “gave a chance to sit down and really think about issues discussed,” was an “incentive to pay more attention to the presentations and bring out any discrepancies in points that were unclear,” and provided an “excellent reflection opportunity.” Others were not comfortable with the grading element, which seemed arbitrary to them. One student wrote forcefully, “The idea here was good. Reflections are important. But the moment you started grading these, the notion of encouraging free, uninhibited discourse is severely ended. Students naturally wonder what it takes to ‘do well.’” These comments led me to abandon grading these reports in the second year.

Table 1: Student evaluation of the course

<table>
<thead>
<tr>
<th>A) This course was designed to explore the context of Biomedical Research. It was my expectation that by the end of this course you would realize that modern biomedical research is a complex endeavor. Indicate how well those objectives were met on a scale of 1 (not met) to 10 (extremely well met).</th>
<th>Median</th>
<th>Mode</th>
<th>Range</th>
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<tr>
<td>9</td>
<td>9</td>
<td>4–10</td>
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B) To achieve those objectives I used several different approaches. How useful were each of these approaches? Indicate their usefulness on a scale of 1 (not useful) to 10 (extremely useful).

1) Modified problem-based approach
Rationale: Students would use a problem to raise issues, frame learning tasks, present information to each other, and evaluate their performance.

2) Discussant reports
Rationale: Students would use this opportunity to reflect and comment on presentations made by other students/guest lecturers.

3) Guest lectures
Rationale: These presentations would serve to provide additional perspectives on issues raised during discussions in the course.

4) Special essays
Rationale: These would provide students an opportunity to explore areas of special interest and thus enhance their appreciation of the complexities underlying biomedical research.

Student opinion about the guest lectures was also divided. I had deliberately tried to find speakers and topics that would provide students with an insight into the joys and frustrations of scientific research. A speaker who had to leave the U.S. during the McCarthy years gave students a valuable insight into the politics of science, and another showed how scientific approaches could be used to “solve” a historical mystery (namely, the disappearance of the Franklin Expedition). Most of these were exciting, but several seemed incomprehensible. I tried as far as possible to schedule lectures that had some bearing on the issues being discussed, but this was not always possible. Some complained that the lectures were too conventional and did not really fit in with the notion of a PBL course.

The students really relished the opportunity to explore issues in depth with the special essay. The last few weeks of the course were set apart so that students could concentrate on their major essay. Each student gave a brief (10–15 min) informal presentation to the others. This sharing of information was very useful because students got to hear about a wide variety of subjects. The discussions following these sessions were usually very lively. The topics chosen ranged widely, as indicated by the list shown in Table 2. Reading and marking these within a short time period was perhaps the most challenging aspect of the course.

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**CONCLUSIONS**

This course sought to provide students in an interdisciplinary program with an opportunity to appreciate the complexities of modern scientific research. Because complex, messy issues can never really be taught in a didactic fashion, it is important that students be involved more actively in their own learning. Thus the modified problem-based approach served the purpose well. I adapted the principles of standard tutorial-based PBL to suit my convenience because I was the sole tutor.

In the small group variant of PBL (the “standard” model), the teacher as a mere information dispenser has been replaced by the tutor as a mentor, facilitator, and guide. Even here, arguments rage over the relative merits of expert versus non-expert tutors (3, 5, 12, 13, 15), and a spectrum of activities has been envisaged from the tutor as a mere facilitator, sitting back to permit students to indulge in their own learning, to more didactic interventionists. Rangachari and Crankshaw (11) have argued that tutors even in the standard model need to take more active roles. Although it is important to shift the locus of control studentward, tutors as faculty members have a societal obligation to see that this is done wisely and well.

In the course described, my “activism” took a different tack. Because I developed the course and was the sole tutor, my involvement was much greater than in other PBL courses. As mentioned earlier, I had an open discussion with the students to obtain a sense of their awareness, attitudes, and interests regarding biomedical research. From this discussion I was able to distill a list of issues that the students considered important for discussion. This provided a frame of reference for writing problems. Given the wealth of information available, I have rarely used a problem more than once.

After the paper problem had been distributed, I often stood at the board and noted down all the points that were raised. This permitted me to draw in students who may have been reticent to speak by asking them what they thought of the issues raised and whether they had points that others had missed. At the next stage, I would help students clarify the learning tasks. As mentioned earlier, there was considerable negotiation among the students. My role was to ensure that the essential elements from the discussions were not lost and that the final list of tasks represented a consensus. I have mentioned already that there were occasions when particular tasks had to be either reframed or abandoned because no students were willing to take them on. If I felt that this was something they ought to have considered, I would try and reintroduce the issues in a different problem at a later date. This enabled me to preserve the essential balance between student- and teacher-centered learning in this course.

This course was designed for liberal arts students to get an appreciation of the context (antecedents and consequences) of biomedical research. The issues explored both with the problems as well as the special essays permitted the students to appreciate the interactions between ideals, individuals, investments, and institutions. I did not really expect students to learn the process of discovery because that is best done by active involvement in the laboratory, field, or clinic.

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**TABLE 2**

Sample titles of essays submitted

- “Putting Science on Trial”: An Inquiry Into the Issues Concerning the Use of DNA Fingerprinting in Courts of Law
- Questioning Cryonics: An Inquiry Into the Scientific Community’s Scepticism Toward the Cryonics Movement and Its Quest for Immortality
- “The Medicine You’ve Been Burning For”: An Inquiry Into Glaxo’s Contribution to the Success of Zantac in the United States
- Not Just Because We Can: Assessing the Validity of Life Science Research in Space
- The Status of the Race Concept in Contemporary Anthropology: A Victim of Political Trends?
- An Inquiry Into the Ethics of Prison Research
- Pluripotent Stem Cells: Should This Research be Federally Funded in the United States?
- A Study in the Legitimation of Knowledge: The “Success” of Acupuncture in North America
- Contraceptive Vaccines and Fertility Control: Exploring the Context in Which a Biomedical Technology is Developed
- An Explanation of the World Health Organizations's Plan to Eradicate Poliomyelitis by the Year 2000
- Telomerase—A Gerontological Breakthrough: An Exploration Into the Social and Economic Implications of Extending the Human Life-Span
Furthermore, it is debatable whether one can teach the process of discovery through a course of this sort. Methodological rules can be provided, but these are better observed in the breach rather than the observance.

Transfer of such approaches to more classic science-based programs may not be easy. Undergraduate science courses are content loaded, and there is a perception that little time needs to be spent for exploring broader social issues. However, as White (18, 19) has shown at the University of Delaware, even in content-loaded disciplines such as chemistry and biochemistry a niche can be carved out for such efforts. His course, Introduction to Biochemistry (Chem 342), is not a survey course and does not emphasize factual material per se. Rather, it focuses on what a biochemist does and why. He uses classic papers such as the 1864 study by G. G. Stokes, “On the Reduction and Oxidation of the Colouring Matter of Blood,” among others to explore understanding of hemoglobin and sickle cell anemia. He uses a problem-based format with a discussion format, and, as in my course, there is no prescribed textbook. Guest speakers, including scientists, historians, writers, and philosophers, are invited to present special topics at the end of the term while students are busy with their term papers. I teach a fourth-year course in pharmacoepidemiology for students in a Pharmacology Program who are receptive to exploring the social dimensions of drug use and dealing with the context in which information is gathered and evaluated. Thus courses emphasizing the context of manufacturing knowledge can be incorporated into science-based curricula.

Approaches such as those described above require both institutional support and motivated students. This university has encouraged interdisciplinary teaching in different ways, and I was able to deal with a group of highly motivated students. Apart from the Arts and Sciences Program, which draws on faculty from a number of other faculties and departments (Medicine, Physics, Mathematics, Statistics, Sociology, Religious Studies), several other interdisciplinary programs (Environmental Health, Peace Studies, Globalization) exist. My students were not only highly motivated but also were sensitized to social issues based on their earlier experiences through Inquiry courses in third world development.

Developing this course has required considerable effort. Apart from the contact time (3 hours per week for 26 weeks), considerable time was spent in reading about a variety of issues, framing problems, collating comments, grading essays, and discussing topics with students. The effort has been rewarding personally, but are such efforts worthwhile?

It may be useful to return to the issues that Snow raised several decades ago. The situation has not become much better. In his revised book, Snow (17) specifically mentioned molecular biology as a subject that should be crucial for all to know about. Since then, biomedical knowledge in general and molecular biology in particular has exploded, and thus the consequences of being oblivious or misinformed are greater. Singer (16) discussed some of these, noting that “when people make choices for themselves, scientific ignorance may expose them to dangers at the personal level. The more serious dangers of scientific ignorance, however, occur when choices are made at the societal level.” She deals with the consequences of such ignorance among lawyers. Similar arguments can be made with respect to other groups that have the capacity to make significant decisions that affect the public. Whether courses that attempt to get students to explore the context of biomedical research will provide them a better basis for dealing with the results of scientific endeavor is difficult to say. Snow noted that “changes in education will not, by themselves, solve our problems: but without those changes we shan’t even realize what the problems are” (Ref. 17, p. 99). That in itself makes the effort worthwhile.

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