(11) Garvey, W. D. *Communication: The Essence of Science*; Pergamon Press, Oxford and New York, 1979.
(12) Lyon, W. S.; Roberts, P. P. "Technical Oral Publications: What Happens to Them". *Anal. Proc.* **1983**, (*London*) *20*, 374.
(13) Braun, T.; Bujdoso, E.; Lyon, W. S. "An Analytical Look at Chemical Publications". *Anal. Chem.* **1980**, *52*, 617A.
(14) Braun, T.; Bujdoso, E.; Lyon, W. S. "Scientometric Study of Health Physics". *Health Phys.* **1981**, *41*, 233.
(15) Bujdoso, E.; Lyon, W. S., Noszlopi, I. "Prompt Nuclear Analysis: Growth and Trends". *J. Radioanal. Chem.* **1982**, *74*, 197.
(16) Bujdoso, E.; Braun, T.; Lyon, W. S. "Information Flow in Analytical Journals". *TrAC, Trends Anal. Chem.* (*Pers. Ed.*) **1982**, *1*, 268.
(17) Garfield, E. *Journal Citation Reports, A Bibliometric Analysis of References*; Institute for Scientific Information: Philadelphia, 1980; Vol. 13, 1980 Annual.
(18) de Solla Price, D. "The Analysis of Square Matrices of Scientometric Transaction". *Scientometrics* (*Amsterdam*) **1981**, *3*, 55.
(19) Burke, C.; de Solla Price, D. "The Distribution of Citations from Nation to Nation on a Field by Field Basis; Computer Calculation of the Parameters". *Scientometrics* (*Amsterdam*) **1981**, *3*, 363.

Two Programs To Further Popular Literacy in Technology†

CARL F. ATEN

Department of Chemistry, Hobart and William Smith Colleges, Geneva, New York 14456

Received August 12, 1985

The structure and content of two programs that were intended to foster technical literacy are described. The first program, for undergradate seniors, worked with the topic "information encoding and information transfer", in terms of the structure of English, the structures of molecules and materials, encoding information in material, and the structure of computers. The second program was for faculty members and emphasized the human, political, and organizational aspects of large-scale, chemically based projects such as environmental monitoring and medical testing. Both programs were interesting to the participants and moderately effective in a short-term way.

INTRODUCTION

The term *scientific literacy* has come to be associated with the communication to the general population of the results of scientific research and its applications. This is an old problem; for example, June 1871: "During the recent siege of Paris, Henry St. Claire Deville, addressed the Academy of Sciences.... Deville stated what all the world has been uttering before him, that France was conquered by the science of Germany. The very discoveries and inventions of their own men were used to destroy them. In seeking an explanation of this disastrous state of affairs, Deville gave two adequate reasons: first that men of science had been overlooked by the Government, and mere politicians appointed in their places; and second, that the members of the Academy had devoted themselves too exclusively to abstract science and left the world to find out what was going on in the best way it could. He proposed as a security that the Institute should appoint committees to discuss all matters related to the government; and at the same time seek to popularize science, and by well-edited publications to familiarize the public mind with the grand discoveries of the day."[1]

With small changes in wording, that could have been said today. The vision of Deville "to popularize science" and "to familiarize the public mind..." is still supported frequently. For example:

(i) A. W. Trivelpiece, "I have a suggestion on how to improve this situation of public understanding of the role of science and technology in our lives. I believe that it is time for scientists and engineers to take more repsonsibility for explaining science and technology in ways the rest of our citizens can understand and appreciate."[2]

(ii) W. R. Benson, "Chemists are interested in telling nonchemists about what chemists do, if it is easy and organized." Benson goes on to recommend subscription to the ACS's radio program "Dimensions in Science" and its tapes.[3]

(iii) The University of California, Berkeley, has begun a 3-year pilot project to provide the public with accurate information on the uses and hazards of chemicals.[4]

In contrast to the viewpoint described above is the thought that the populace probably cannot be informed well enough to participate in public debate on essentially technical issues. This view was stated nicely with respect to research on recombinant DNA:

(iv) Francis Crick, "I live near a small California township called Del Mar, and when the housewives are spending their time worrying about recombinant DNA, I really think it has gone too far."[5]

A very short list of topics of public debate is the following: transport of chemicals and of chemical waste; storage and disposal of chemical waste; nuclear power generation; nuclear fuel reprocessing; acid rain; long-term changes in the atmosphere—warming, ozone; genetic engineering; pesticide use; medicine development and use; should we drink coffee or not?; should we exercise or not?

These topics and many others are matters of general concern. Some are controlled by laws now, and more will be controlled by laws in the future. In what ways and to what extent can the populace participate in shaping public policy in technical matters? When we recall the difficulty chemists have communicating with each other, the vision of Deville described above seems clearly to be unattainable, but the view expressed by Crick is unacceptable. What, then, is possible; what can we do? Clearly, we must inform people as well and as much as we can about technology. But, equally clearly, it is impossible for large numbers of people to be well informed about any particular technolgoy. We must be sensitive to the kinds and amounts of technical information the public can use. The populace will always have to rely on expert witnesses and must cope with the following questions:

(i) Which experts should be believed?

(ii) Of what is told by the experts, what should be believed?

(iii) What is the larger social framework within which any given technical problem must be seen and for which the technical experts have no special help to offer?

Scientists must continually seek ways of helping people with these questions but should probably not try to teach the technology itself in any particular case. For example, the usual

† Presented before the Division of Chemical Information, 189th National Meeting of the American Chemical Society, Miami Beach, FL, April 29, 1985.

0095-2338/86/1626-0052$01.50/0

Table I. Distribution of Students in Senior Colloquium by Academic Department and by Topic Category

no.	department	no.	topic category
2	Art	5	genetics and evolution
5	Biology	5	thinking and ideas
6	Chemistry	2	memory
4	Economics	2	sensory perception
4	English	3	personal behavior, nonverbal
1	Geoscience	4	social communication, entertainment
4	Mathematics	3	maps and pictures
1	Philosophy	3	architecture
2	Psychology	2	advertising
2	Sociology	3	games and computers
4	individual major	3	birds, bees, and whales

undergraduate curriculum in chemistry does stress chemical technology and does contribute to the development of good chemists. However, such a curriculum is probably not much help with many social–technical questions. Two programs are described below that have been offered at Hobart and William Smith Colleges, which were addressed to general audiences and which were intended to provide a general understanding of some aspects of modern technology and its social impact. Although these programs were held on a college campus, that is not a necessary condition. Study groups anywhere could use these communication pathways.

THE PROGRAMS

The Senior Colloquium. This program for senior students extended over two quarters (20 weeks total) with usually two or three meetings per week. It was one of about 20 colloquia on all sorts of different topics offered to senior students; each student was required to enroll in a colloquium but was free to choose which one or to propose a new one. Our title was "Information and Life", and the topic was "Information Encoding and Information Transfer". There were no prerequisites for admission, and students with majors in a wide range of departments participated. Three faculty members, one from each of the Departments of English, Philosophy, and Chemistry, met with the 10–15 students who enrolled. During the first term, the faculty lectured, assigned material to be read, and tried to arouse discussion. In addition, each student was urged to select a pertinent topic to pursue on an individual basis during the second term. The schedule we followed during the first term was

week	topic
1–4	structure of English language
5–8	encoding and transfer of information in natural materials and in man-made communications systems
9–10	a broad perspective: (i) information processing within living things; (ii) interactions between organisms and their environs
11–13	examinations and vacation
14–24	student reports on individually chosen topics; three oral presentations and one final, written report

The distribution of students by academic major is shown in Table I. Also, included in Table I is a list of areas in which the titles of the students' individual topics for the second term may be grouped. The students were drawn from 10 academic departments, and a few had individual majors (nondepartmental). The topics studied in the second term were quite varied. They were generally not chemical topics, but perhaps half might be regarded as topics in natural science while the rest were more social or artistic in content.

The principal material we read and discussed in the first 10 weeks is listed in Table II. Obviously with so much material, the books and articles were usually neither read completely nor discussed thoroughly. Our intent was to indicate the nature and scope of each subtopic and to read enough about it so that an interested student could pursue it further. The immediate goal was to stimulate ideas for the individual projects in the second term.

In the first 4 weeks of the term an overview of certain aspects of human language was developed. Discussion began with theories of phonemes (elementary sounds) and morphemes (elements of meaning), went on to phrase and sentence structures, and finally went on to syntax and models of sentences. In models, or diagrams, of sentences one tries to show the relations between phrases and words in a hierarchical pattern. A similar scheme has been used in a clustering approach to pattern recognition. Also, one can argue that chemical combining rules play a role similar to rules of

Table II. Principal Reading List for Senior Colloquium

Books
de Saussure, F. *Course in General Linguistics*; Baskin, W., Transl.; McGraw-Hill: New York, 1959
Language as a Human Problem; Haugen, E.; Bloomfield, M., Eds.; Norton: New York, 1974
Fromkin, V.; Rodman, R. *Introduction to Language*; Holt, Rinehart and Winston: New York, 1978
Raphael, B. *The Thinking Computer*; W. H. Freeman: San Francisco, 1976
Piaget, J. *Structuralism*; Maschler, C., Transl.; Harper and Row: New York, 1968
Piaget, J. *Biology and Knowledge*; Walsh, R., Transl.; University of Chicago Press: Chicago, 1971
Kuhn, T. S. *Structure of Scientific Revolutions*; University of Chicago Press: Chicago, 1970
selected parts on several general chemistry texts on periodic table, atomic combining rules, crystal structures, molecular symmetry, and polymers
Articles from *Scientific American*
Bragg, Sir L. "X-ray Crystallography". **1968**, *219* (1), 58–70
Lambert, J. B. "Shapes of Organic Molecules". **1970**, *222* (1), 58–70
Hubbard, R.; Kropf, A. "Molecular Isomers in Vision". **1967**, *216* (6), 64–76
Koshland, D. E., Jr. "Protein Shape and Biological Control". **1973**, *229* (4), 52–64
Rich, A.; Kim, S. H. "Three-Dimensional Structure of Transfer RNA". **1978**, *238* (1), 52–62
Luria, S. E. "Recognition of DNA in Bacteria". **1970**, *222* (1), 88–102
Schopf, W. "Evolution of the Earliest Cells". **1978**, *239* (3), 110–138
Lewontin, R. C. "Adaptation". **1978**, *239* (3), 212–230
Iverson, L. L. "Chemistry of the Brain". **1979**, *241* (3), 134–149
Hubel, D. H; Wiesel, T. N. "Brain Mechanisms of Vision". **1979**, *241* (3), 150–162
Harmon, L. D. "Recognition of Faces". **1973**, *229* (5), 70–82
Gillam, B. "Geometrical Illusions". **1980**, *242* (1), 102–111
Meindl, J. D. "Microelectronic Circuit Elements". **1977**, *237* (3), 70–81
Oldham, W. G. "Fabrication of Microelectronic Circuits". **1977**, *237* (3), 110–128
Hodges, D. A. "Microelectronic Memories". **1977**, *237* (3), 130–145
Lewis, H. R.; Papadimitriou, C. H. "Efficiency of Algorithms". **1978**, *238* (1), 96–109
Pippenger, N. "Complexity Theory", **1978**, *238* (6), 114–124
Hellman, M. E. "Mathematics of Public-Key Cryptography". **1979**, *241* (2), 146–157

grammar. Some of the limitations of these models were rather interesting and provided a basis for comparison with physical models. Attention was given to the concept of grammaticality and to problems of interpretation as suggested, for example, by ambiguous sentences. Finally, a model for communication was considered in an attempt to unify the ideas that had been discussed.[6]

In the following 4 weeks, discussions centered on information encoding and information transfer in natural materials and in man-made communication systems. This began with a description of information in terms of binary codes and went on to develop a chemical view of materials touching on the topics of atomic composition, crystal structure, molecular structure, molecular isomers, and genetic control of protein synthesis. Several general chemistry texts were made available to students who had not studied chemistry previously. Next, the subject of electrical circuits, their construction, and their manipulation as communications systems was discussed. The spirit of these discussions is represented well by the *Scientific American* articles listed in Table II. Last, language translations by computers and efforts to make robots were considered.

In the final 2 weeks of the term, we tried to develop a broad perspective of the subject in terms of (i) the interactions of living things with their environments and (ii) information processing within living things. This led to discussions of social culture, creation of scientific theories, and the role of models in our thinking.

As noted above, the entire second term was devoted to oral progress reports by the students in two or three rotations and the preparation of a final written report.

The intellectual content of the program consisted primarily of structural comparisons of aspects of language, chemical science, and electronics or computers. In the following seven paragraphs, let us consider a grouping of ideas by content rather than chronology and note formal similarities.

(1) What are the structural units (elements) of codes? The most elementary unit of language is the phoneme or element of sound. Usually, these do not mean much by themselves and are combined to make words, which in turn are combined into phrases, sentences, paragraphs, etc. Although the quest for elementary particles of material seems endless, the atoms offer a convenient starting place. Then, the sequence of combinations might be taken as atoms, molecular formulas, reaction equations, and synthesis schemes. In electronics, different structural units may be identified depending on whether one is concerned with the hardware or with the encoding system. Although these cannot be independent, they are different. In a telegraph system using Morse code, the elementary hardware units might be taken as a key/receiver, which could be combined with others to make a network. At the same time, the encoding system would be based on dots, dashes, and spaces, which are combined to represent letters, words, etc.

(2) How is information encoded? In language, we speak or write words, phrases, and sentences to represent ideas. However, the richness of the encoding in language is apparent immediately. With language we may be calm and direct, or sarcastic, or clever as in jokes and puns, or exciting, or imperious, or we may lie. We couple all sorts of gestures and poses with speech, but not with writing, of course. The differences between formal written English and casual speech are a substantial stumbling block for students. In materials, encoding may taken various forms. The elementary composition of material may be taken as a sort of code. The more interesting schemes we have identified are usually based on molecular formulas, shapes, and sequences in polymers. A fundamental aspect of vision depends on a cis–trans isomerization; insects leave chemical trails or find mates by means of chemical emissions; our bodies regulate themselves by enzyme-controlled reactions in which molecular size and shape are important. In electronics, the principal schemes of encoding may be classed as analog or digital, amplitude or frequency modulation and some sort of binary system, respectively.

(3) What kinds of information can be encoded? For this question to make sense, one must specify the partners to the communication or accept a very limited definition of information. In vision, we may limit ourselves to the binary option of light or dark. Or, we may enlarge the matter to include the color of the light and its pattern. Finally, and usually, we ask for an identification of the pattern.

(4) Where does the meaning lie in a message? Here, one must specify not only the partners to the communication but their intent. The question is very interesting but virtually unanswerable. One is tempted to answer "somewhere between the beginning and the end," but that completely overlooks an important point. The very act of communication and/or the choice of method may be as important as the encoded message. Years ago in different circumstances, a long distance telephone call was a matter of considerable importance in itself. Now it is just another call. In the previous example, (3) above, the meaning in the communication might lie beyond the sequence listed; if the pattern were identified as someone's face, the meaning might reside in whether the face is or is not smiling. Chemical communications are usually more straightforward, and the meaning is obvious or implied in the communication: pheromone emission is a call for a mate; enzymes respond to molecular concentrations and shapes; protein synthesis may be regarded as a very complicated communication, but its meaning is simply to duplicate a pattern.

(5) What different levels of meaning exist? This question asks that a communication be viewed in a large context. Is pheromone emission by an insect only a clever exercise in chemical synthesis and detection? No, it is also a call for a mate, and it is even more. It is a vital step in the survival of the species. Perhaps, it is a step in the survival of several interdependent species.

(6) What are the effects of noise in information transmission, reception, and processing, and what may be done either to reduce noise or to reduce its effects? Noise, or error, is an ever present problem that may be illustrated in many ways. In language, it might be background sound superposed on a message, it might be omissions from the message, or it might be grammatical errors in the message. Chemical noise is usually called by other names but would be things like side reactions and local fluctuations in conditions. Poisoning of an enzyme may be regarded as an error in communication in which a compound was mistaken for substrate. The principal defense against noise and error is redundancy. Language has substantial redundancy built into it. An amusing demonstration of this is to take a written line, preferably a sentence, and strike letters from it, first every tenth, then ninth, eighth, etc. until the sentence becomes unintelligible. In electronic data transmission, the advantage in accuracy of digital processes over analog have been striking. But this advantage is bought for a price; digital transmission is more redundant in the sense that more characters are used for a given representation than in the corresponding analog representation.

(7) We tried to summarize these ideas in terms of Piaget's view of structure as it might be applied to organisms.[7] The essential feature of this model is that living structures are dynamic rather than passive. They must be capable of transformational procedures and must constantly process new material and ideas. Further, a structure must be complete and self-regulating. A language is such a structure in that words are constructed without any particular relation to the objects or actions they represent. The word *conference* is a noun

Table III. Principal Reading List for Faculty Seminar

Books

Moore, D. S. *Statistics*; W. H. Freeman: San Francisco, 1979
Committee on Chemistry and Public Affairs *Chemistry in Medicine*; American Chemical Society: Washington, DC, 1977
Committee on Environmental Improvement *Cleaning Our Environment. A Chemical Perspective*, 2nd ed.; American Chemical Society: Washington, DC, 1978

Articles in *Analytical Chemistry*

Morrison, G. H. "Evaluation of Lunar Elemental Analyses". **1971**, *43*, 22A–31A
Cooper, J. W. "Errors in Computer Data Handling". **1978**, *50*, 801A–812A
Barnard, A. J., Jr.; Mitchell, R. M.; Wolf, G. E. "Good Analytical Practices in Quality Control". **1977**, *50*, 1079A–1086A
Horwitz, W. "Good Laboratory Practices in Analytical Chemistry". **1978**, *50*, 521A–524A
Amore, F. "Good Analytical Practices". **1979**, *51*, 1105A–1110A
AOAC Committee on Collaborative Studies "Collaborative Study Procedures of the AOAC". **1978**, *50*, 337A–340A
Vandenbelt, J. M. "Standards in Analytical Instrumentation". **1977**, *49*, 386A–398A
Anders, O. U. "Representative Sampling and Proper Use of Reference Materials". **1977**, *49*, 33A–36A
Roberts, R. W. "The Other Face of the Measurement Base". **1975**, *47*, 648A–656A
Cali, J. P. "The NBS Standard Reference Materials Program: An Update". **1976**, *48*, 802A–818A
Mitchell, J. W. "Ultrapurity in Trace Analysis". **1973**, *45*, 492A–500A
Hirschfeld, T. "Limits of Analysis". **1976**, *48*, 16A–30A
Hwang, J. Y. "Trace Metals in Atmospheric Particulates". **1972**, *44*, 20A–27A
Hertz, H. S.; May, W. E.; Wise, S. A.; Chesler, S. N. "Trace Organic Analysis". **1978**, *50*, 428A–436A
Budde, W. L.; Eichelberger, J. W. "Organics in the Environment". **1979**, *51*, 567A–574A
Donaldson, W. T.; Garrison, A. W. "Reporting Impurities in Commercial Products". **1979**, *51*, 458A–462A
Ehmann, A.; McKinney, W. J.; Reinsfelder, R. E.; Saliman, P. M.; Silveira, E. J.; Golton, W. C.; Donaldson, W. T. "Master Analytical Scheme Revisited". **1979**, *51*, 985A–989A
Novotny, M. "Capillary Gas Chromatography". **1978**, *50*, 16A–30A
Janssen, W. F. "The Cancer Cures; a Challenge to Rational Therapeutics". **1978**, *50*, 197A–202A
Suffet, I. H.; Cairo, P. R. "In Search of the Cause of Legionaires' Disease". **1978**, *50*, 875A–881A
Glazko, A. J. "Analytical Methodology in Drug Metabolism Studies". **1978**, *50*, 632A–639A
Barnard, T. W. "Automation in Atomic Spectroscopy". **1979**, *51*, 1172A–1178A

subject to the rules governing nouns and does not in itself have any connection with real meetings. Similarly, chemical structures and stoichiometry exist in accord with the rules of bonding without reference to chemists or any other external agency. With living organisms, either individuals or groups, this model fits approximately but not exactly. There are interactions between individuals and between groups; in general, there is a feedback loop between any structural unit and its environment, and each affects the other. Life may be viewed as a network.

Most of the questions or topics listed above are either unanswerable or are too large to be treated in any great detail in the time that was available. However, we did touch on each of them to the extent that we could.

The first term tended to be somewhat discouraging because of the lack of overt student response to the readings and to the faculty presentations. This was probably due to several factors; the students did not know each other nor did they know each of the faculty members, the variety and amount of reading was difficult, and last, they simply did not understand the point of the program. A few students even wondered why they should be literate in science. However, as the second term proceeded and the students gave and heard oral progress reports, there was a blossoming. They had indeed learned something and were able to incorporate new ideas into various kinds of patterns and topics. If we judge the program as an opportunity for students to explore the logical, analogical, and metaphorical (substitutive) relationships among various "languages" or codes that are central to human life, then that goal was met with some success. The discussions by the students and their oral presentations were most encouraging, and a number of the final reports were of high quality.

The paper written by one person may be useful example. The person majored in English and took no science courses but was receptive, thoughtful, and outgoing. The paper dealt generally with the role of rules, or the conceptual framework, within which various activities are pursued. In particular, it was concerned with art and science through a comparison of painting with mapping. It appears that the person took a substantial intellectual step and acquired an appreciation of science that was absent before the program.

The Faculty Seminar. This was a group of six faculty members from the Departments of Chemistry, Physics, Mathematics, Religious Studies, and English (two persons; a poet and a part-time dean). The group met about 20 times over a period of seven months. The title was "On the Politics and Analytical Chemistry of Technical Information", and generally, we were near the topic "what is the role of analytical chemistry in modern society?" Books and articles from *Analytical Chemistry* that were read and discussed are listed in Table III.

A large part of our discussion was directed toward the myth that scientists in general, and analytical chemists in particular, deal with facts. We began by spending two afternoons carrying out two general chemistry laboratory exercises. The first was a comparison of the potentiometric titration of $CuSO_4$(aq) by NaOH(aq) with the reverse titration. The experiment is interesting because the reaction products are different in the two cases, $Cu_4(OH)_6SO_4$ and $Cu(OH)_2$, respectively. The second experiment was the determination of the total normality of anions and of cations in lake water by ion exchange and titration with standard acid and base. These results were compared with the conductance of the lake water. People were surprised to obtain two different products from the same reactants and to find that we had six slightly different results for every measurement although the starting materials were the same. And finally, the relation between the conductance result and the titration results for the lake water was not obvious although both measurements depended upon the same ions. These experiments were followed by a careful reading of a book on statistical concepts and partial readings of the books *Chemistry in Medicine* and *Cleaning the Environment*. The articles from *Analytical Chemistry* were read along with the books. The principal ideas considered were as follows:

Analytical chemical results are not exact; they may be bad; their reliability depends strongly on both who obtained them and the method used.

How do laboratories and individual chemists try to protect themselves from generating bad data?

What are some modern instrumental methods of analysis?

What are the prospects for widespread applications of chemical analyses?

How does one sample "the environment"?

What do analyses cost?

How are large bodies of analytical data handled?

Some particular questions that arose in connection with the books were as follows.

(i) For *Statistics*:

What is "random sampling"?

What variation may accompany different sample sizes?

Experimental design: minimum cost, random sampling, sample integrity, and interferences. This was of particular interest again in connection with drug testing and development.

What are proper ways of comparing and presenting results?

Relations between distributed results and average values.

Statistical correlations.

(ii) For *Chemistry in Medicine*:

What is the history of drug use?

Can useful drugs from natural products be identified via folklore? The humanists felt aggressive on this point and argued strongly that society has been and is being manipulated by the medical/chemical establishment.

What are the ethics of testing drugs?

How do hospital laboratories operate?

(iii) For *Cleaning the Environment*:

On pesticides; the humanists argued strongly for "natural" control systems.

What is the proper role of chemical technology in our society?

How can industrial chemicals and chemical wastes be controlled?

In summary, the purpose and activity of the seminar was to consider some aspects of the rapid growth and impact of technical information and to discuss the creation, assimilation, validity, and utility of some types of information derived from chemical analyses. It was intended to acquaint the participants with (i) a few important instrumental techniques and to note the multiplicity of techniques, (ii) the scope of the measurement problem, (iii) problems of information storage, retrieval, and processing, and (iv) a few exemplary real problems.

Of this small group, one person whose field is in the humanities, has built on our effort and has been instrumental in developing and teaching a required general-education course for freshmen based on computer technology and applications.

DISCUSSION

The intent of the programs described above was to teach the language, a few fundamental ideas, and the general methods of operation of science and technology. Our treatment was essentially nonquantitative. This is to be recommended since many people are not inclined to think quantitatively and reject a quantitative approach. However, completeness and accuracy of thought need not always be accompanied by numbers and equations. Completeness and accuracy are characteristics required for learning a language, music theory or music for performance, ballet, sports, and many other topics. The distinction to be made is between accurate and sloppy rather than between quantitative and qualitative. A closely related difficulty might be called "the role of details". It is difficult to discuss a topic without knowing some detailed information about it. However, one must avoid bogging down in details or obscuring in topic with them.

An interesting contrast in the two programs occurred in the area of ethical questions. Largely, the students avoided ethical or personal matters. For example, the communication associated with love or conflict simply was not considered. However, a large part of the faculty seminar dealt directly, and with some heat, with ethical questions. Probably this difference in emphasis lies in the greater age and experience of the faculty members.

It is difficult to evaluate programs of this sort in a clear objective manner. The intent was to guide the thinking of the participants toward technological issues and to enable them to think more clearly about such issues. To evaluate the real worth of the programs, it would be necessary to examine the thinking both of the participants and of a control group for perhaps 20 years, an absurd prospect. It was our experience during the programs that the participants acquired more facility in reading and thinking about technological issues and discussed them more carefully as the programs proceeded. There was clear progress. Of course, individuals in the groups displayed large differences in ability and response to these issues, depending on personal values and point of view.

A recent poll of the participants (40) yielded responses from six persons, which may be summarized:

are you trained in science	3 yes; 3 no
was program beneficial	6 yes
has program affected your reading	2 yes; 4 no
have you an interest in particular issues	2 social effects of computers; 2 pollution of environment, business isues, regulation, nuclear arms control, land use, difficulties of chemical analysis
most helpful aspect of program	interdisciplinary connections, *but* structure was not obvious enough; laboratory experience was very helpful in seeing subtleties of chemical analysis

However, such programs are only one step in a long process that must be sustained by the individual user. It is important that scientists watch for opportunities to describe or illustrate science and act on them whenever possible so as to encourage such continued effort.

As indicated above, we dealt more with questions than with answers. However, if important questions can be identified clearly, and phrased correctly, then the problems that prompted them may not seem so difficult.

The prospects for programs like these seem good. They are not especially difficult to offer; they require no special equipment and so can be offered anywhere; and they are intellectually accessible to many people. They can address socially pertinent topics and can be interesting and enjoyable. The best result of this sort of program probably is to enable the participants to understand the merits of arguments offered by experts in debates about technology and, in some cases, to form reasonable judgements about them.

REFERENCES AND NOTES

(1) "Popularizing Science". *Sci. Am.* **1871**, *24* (3), 360.
(2) Trivelpiece, A. W. *Chem. Eng. New* **1984**, *62* (27), 3.
(3) Benson, W. R. *Chem. Eng. News* **1984**, *62* (24), 4.
(4) Baum, R. *Chem. Eng. News* **1984**, *62* (22), 29–30.
(5) Golden, F. *Time* **1983**, *Oct. 3*, 67.
(6) Pierce, J. R. "Communication". *Sci. Am.* **1972**, *227* (3), 31–51.
(7) Piaget, J. *Structuralism*; Maschler, C., Transl.; Harper and Row: New York, 1970; pp 1–16.