judgment and decision-making see [P. Slovic, B. Fischhoff, S. Lichtenstein, in *The Annual Review of Psychology* (Annual Reviews, Palo Alto, Calif., in press), vol. 28]. See also M. Kaplan and S. Schwartz, Eds., *Human Judgment and Decision Processes* (Academic Press, New York, 1975); W. Edwards, M. Guttentag, K. Snapper, in *Handbook of Evaluation Research*, E. L. Struening and M. Guttentag, Eds. (Sage, Beverly Hills, Calif., 1975), vol. 1; R. A. Howard, in *Proceedings of the Fourth International Conference on Operational Research* (Wiley-Interscience, New York, 1966); H. Raiffa, *Decision Analysis: Introductory Lectures on Choices Under Uncertainty* (Addison-Wesley, Reading, Mass., 1968).
15. Can the adversary system produce this confusion of roles at the national level, and does it have similar negative effects? Apparently it can, and does. For example, in Polsby's review of Boffey's book, Polsby (7, p. 666) states: "Boffey notes, in criticizing a National Academy of Engineering committee on pollution abatement, that it was no more qualified than any other group of citizens to judge what should be 'wise' public policy." (In this instance, Boffey argues that scientists overstepped their bounds and should have confined their role to presenting the facts.) "Sound doctrine," observes Polsby, "and yet Boffey criticizes another of the Academy's committees for taking on an assignment pertinent to a naval communications project that did not include evaluating its 'desirability,' and for not venturing to raise 'questions as to the basic worth' of the space shuttle program." (In this instance, Boffey argues that scientists failed to help form social policy and thus failed in their responsibility to the public.) Thus, concludes Polsby, "the Academy is damned if it does pronounce on the overall wisdom of public policies, and damned if it doesn't."
16. Public Broadcasting Service, "Black Horizons," 16 February 1975.
17. K. R. Hammond, T. R. Stewart, L. Adelman, N. Wascoe, *Report to the Denver City Council and Mayor Regarding the Choice of Handgun Ammunition for the Denver Police Department* (Report No. 179, University of Colorado, Institute of Behavioral Science, Program of Research on Human Judgment and Social Interaction, Boulder, 1975).
18. To determine the relative importance a person places on each characteristic, linear multiple regression analysis was performed to obtain the beta weights on each of the three judgment dimensions, or factors. The absolute value of the beta weight for a factor was then divided by the sum of the absolute values of the beta weights over all factors to determine the relative weight, or importance placed on each factor. The relative weights were displayed on the computer console. For technical details on the procedure see [K. R. Hammond, T. R. Stewart, B. Brehmer, D. O. Steinmann, in *Human Judgment and Decision Processes*, M. Kaplan and S. Schwartz, Eds. (Academic Press, New York, 1975)].
19. The judgment dimensions were defined as follows. (i) *Stopping effectiveness*: the probability that a 20- to 40-year-old man of average height (5′10″) and weight (175 lbs) shot in the torso would be incapacitated and rendered incapable of returning fire. Judgments ranged from 0 to 100, indicating, on the average, how many men out of 100 would be stopped by a given bullet. (ii) *Severity of injury*: the probability that a man, as described above, shot in the torso would die within 2 weeks of being shot. (iii) *Threat to bystanders*: penetration was defined as the probability that a bullet would pose a hazard to others after passing through a person shot in the torso at a distance of 21 feet. Ricochet was defined as the probability that a bullet would pose a hazard after missing the intended target at a distance of 21 feet.
20. The separation of stopping effectiveness from injury that is indicated in the graph for bullet 9 was not due to inconsistencies and inaccuracies in the experts' ratings. The three medical experts agreed that the shape of the temporary cavity is an indicator of differences in severity of injury for bullets with the same stopping effectiveness. More severe wounds are produced by bullets that have a long, wide temporary cavity; less severe wounds localize the maximum diameter of their temporary cavity and do not penetrate deeply. According to all three experts, a temporary cavity that reaches a maximum diameter of 10 to 15 cm at 5 to 7 cm from the surface, and does not penetrate more than 15 cm, would provide the best compromise between stopping effectiveness and survivability.
21. The time, manpower, and cost of the handgun study were as follows. (i) The project was completed in 6 weeks and (ii) research personnel included four people of whom one worked full time. Total cost, including salaries of the project staff, did not exceed $6000; an additional $3500 was required to pay the travel and consulting costs of the ballistics experts.
22. For examples of the application of a hierarchical framework, see K. R. Hammond, J. Rohrbaugh, J. Mumpower, L. Adelman, in *Human Judgment and Decision Processes: Applications in Problem Settings*, M. F. Kaplan and S. Schwartz, Eds. (Academic Press, New York, 1976).
23. J. Rawls, *A Theory of Justice* (Harvard Univ. Press, Cambridge, Mass., 1971).
24. Supported by National Institute of Mental Health grant MH-16437. We thank S. Cook, D. Deane, and B. Fischhoff, among many others, for their help.

# Computing in the Liberal Arts College

## At Dartmouth, writing a computer program is part of becoming a liberally educated person.

John M. Nevison

At Dartmouth College about half of the courses that use computer programs are in the social sciences or the humanities. Such use requires that undergraduate computing be discussed in a context broader than the sciences alone. Writing and using a computer program has become a general skill capable of wide application in a liberal arts education. Last year's course computing involved one-quarter of the faculty and three-quarters of the students.

This widespread activity is the result of three fundamental factors. First, Dartmouth's convenient computer system allows a student to learn to write a computer program in a few hours. Second, the system, like the library, is open to the whole campus. Third, the system has been supplying these services to the campus for 10 years. The purpose of this article is twofold: to provide evidence from Dartmouth College that when such a computer system is made widely available it will be widely used, and to suggest that learning to write a computer program must now be considered part of becoming a liberally educated person.

The subject is a timely one for several reasons. Recent data at Dartmouth suggest that computing will mature after a period of growth. This mature use provides several measures against which a college or university new to educational computing can gauge its own growth. Also, computing at Dartmouth grew up largely before the fragmenting forces of minicomputers and access to national networks increased the difficulty of collecting data on equipment use (*1*). Therefore, the records of the central computer at Dartmouth provide a good estimate of the campus computing activity, past and present, and yield a more precise picture than that possible on many campuses.

In the discussion that follows, data on the maturing use of computing in instruction lead to a quantitative picture of what computing means to the faculty member and to the student. The results of a recent series of interviews with instructors who use computer programs in their courses support the quantitative description of use and suggest that the ability to write a computer program is essential for the science student and extremely convenient for the social science student. The data show that students at Dartmouth frequently encounter the use of computer programs in their studies and that the ability to write a program is a skill they are likely to acquire. Finally, the discussion concludes with the suggestion that the appropriate term to describe the spread of this skill is the *computing literacy rate*.

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## Background

For the past 10 years Dartmouth College has provided students and faculty with what the President's Science Advisory Committee described as "adequate" computing in its 1967 report *Computers in Higher Education*, also known as the Pierce report (*2*). Adequacy in this report involved four criteria: ease of use, reliability, fast response, and satisfactory consulting support (*2*). Dartmouth began in 1964 with a system that featured good diagnostic messages and an easy-to-learn language, Basic. The service was reliable. In the past 2 years more than 98 percent of the scheduled 7 a.m. to 2 a.m. day was available for use (*3*). The system had a fast turnaround time. On an interactive time-sharing system one rarely waits more than a few seconds to see results. Through a newsletter, a small number of consultants, and short training courses, the computation center provided consultation and instruction to the campus. To the Pierce report's definition of adequate the Dartmouth system added a fifth criterion, free access. Students and faculty have used the computer as they have used the library—without financial inhibition. Details on the development of the original system and a discussion of the free-access policy and its implications have appeared (*4, 5*).

During the year from summer 1974 through spring 1975, the computing machinery consisted of two Honeywell 635 central processing units, 262,144 36-bit words of magnetic core memory, 400 million bytes of disk storage, and two communication computers. This is a large computer system similar to others in use in higher education around the country (*5*). It supports heavy use in research, development, administration, and graduate schools. Only 20 percent of the resources were used in the instructional computing discussed here (*6*). The equipment differs from that in many other systems because it is easily available to students. Last year, computing power was available to campus users through 350 terminals that could connect to 270 ports. The campus was saturated with terminals.

Figure 1 shows that the resultant instructional use was broad. The computing equipment was used in courses involving one-quarter of the faculty and three-quarters of the students. The data presented in Fig. 1 were gathered from "left to right." The teaching faculty was surveyed to discover who had any experience with computing and who had taught a course that made use of computing within the year. Each of the 97 instructors who had used some computing was interviewed. A list was compiled of the courses in which computer programs were used and checked against student records to find the 2738 individuals who had taken the courses. The names of these students were also checked against computer billing records, and an additional 550 computer users who were not in these courses were found. The classes of 1975 through 1978 comprised 3763 students (*7*).

## Maturing Use

The growth of computing among the students and faculty at Dartmouth has been organic. It has proceeded at an unhurried pace where students and faculty learn to program largely on their own. The use has been encouraged by a two-lecture introduction given to all students in elementary mathematics courses. These lectures were optional and occurred outside regularly scheduled classes. The mathematics courses required that students complete four computer programs and turn in successful runs to their instructor. This modest effort of two lectures and four programs constitutes most students' formal introduction to programming at Dartmouth College (*2*, p. 76). The faculty was encouraged to attend the regular lectures given each term by the computation center staff, but was offered no special program of its own. Over the years the student and faculty use has grown as the result of needs arising from normal academic pursuits (*8*).

When this unpressured, organic growth slows, it indicates a maturing use of computing. Figure 2 shows how the percentage of undergraduates using the computer has leveled off at 80 percent a year. Additional evidence suggests that this leveling represents real stability. The breakdown of the 80 percent by class is: freshman, 93; sophomore, 79; junior, 76; and senior, 69 percent. These figures are substantially the same as a similar set compiled in the fall of 1972: freshman, 91; sophomore, 79; junior, 78; and senior, 71 percent (*9*). So, in addition to a stable gross percentage use, the

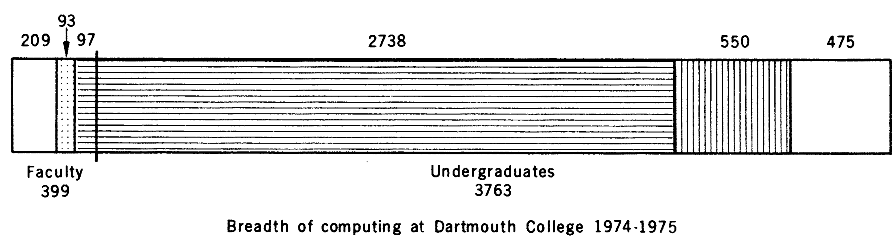
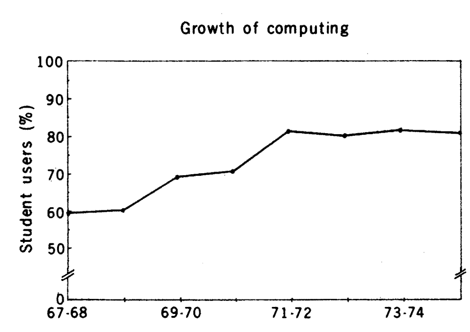



Fig. 1. One-quarter of the faculty and three-quarters of the students were in courses where computing was used in the last year (horizontal shading). Other faculty members have had experience with computing (dotted area). Other students have also used the computer during the year (vertical shading). The teaching faculty numbered 399 for the year summer 1974 to spring 1975; the classes of 1975 through 1978 numbered 3763.



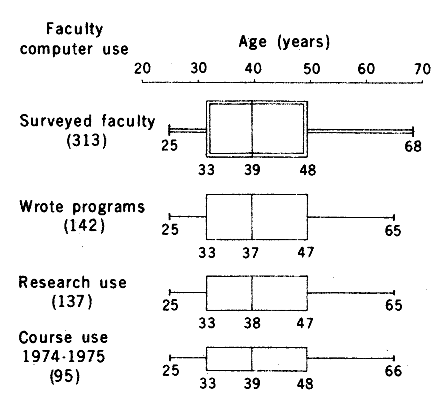




Fig. 2 (left). Undergraduate use has leveled off at 80 percent of the student body. Growth of computing from 1967 to 1975 shows that the proportion of the undergraduates using the computer has been relatively constant for the last 4 years. Fig. 3 (right). Age does not influence computing use. The age distribution of the surveyed faculty (double box) is similar to that of three classes of computer users: those who have written programs, those who have used computing in their research, and those who used computing in courses during the academic year 1974–1975. The five numbers associated with each figure represent (left to right) the low value, the low quartile, the median, the high quartile, and the high value of each group. The middle half of each distribution is enclosed in the box whose area is proportionate to number of individuals enclosed. Missing age data excluded from the samples (from top to bottom): 19, 6, 8, and 2 persons.

Table 1. Dartmouth faculty computing experience. Out of the faculty's research computing and past experience writing computer programs grow course applications for the academic year 1974–1975. The faculty computing literacy rate is 45 percent. Computing is important to both the science and the social science faculty and of some interest to those in the humanities. The "yes" responses represented in the last three columns were to the questions: "Have you ever written a computer program?," "Do you use computing in your research?," and "Did you use computing in any of the courses you taught in the last year?"

| Group | Surveyed faculty (No.) | Wrote a program (%) | Used in research (%) | Course use, 1974–1975 (%) |
|---|---|---|---|---|
| Humanities | 127 | 12 | 12 | 9 |
| Social sciences | 99 | 48 | 57 | 30 |
| Sciences | 106 | 80 | 70 | 53 |
| College | 332 | 45 | 44 | 29 |
| (No response) | (67) | | | |
| (Total faculty) | (399) | | | |

class breakdown of this use has also remained the same for several years. Student use has matured.

Computer records do not provide a clear history of faculty use that may be compared from year to year. However, the recent survey of the faculty provides a different and quite unexpected argument for the maturity of their use. Computing in instruction, like many innovations, began among the younger faculty. They first encountered it during their graduate work and became the first to employ it in their teaching. The authors of the Pierce report acknowledged this, but went on to say (*2*, p. 38): "It has been pointed out that a relatively short interval of intense training can prepare a faculty member to make effective use of the computer, and it is clear that many faculty members from all age groups will—and should—want to become conversant with the computer." So, when age no longer plays any role in determining who among the faculty uses computing, that faculty would be well on the way to a mature appreciation of these new techniques.

Figure 3 compares the age distribution of the whole faculty at Dartmouth to the age distributions of three kinds of users—those who have written a computer program, those who have used computing in research, and those who have used computing in the courses they taught in the last year. In all three cases there is no significant difference in the age distribution (*10*). Age no longer plays any role in determining who on the Dartmouth faculty uses computing. Faculty use has matured.

Since usage has matured at Dartmouth, other campuses now in the early stages of computer growth might well ask what this mature use can mean to the faculty member and to the student (*11*).

## Computing and the Instructor

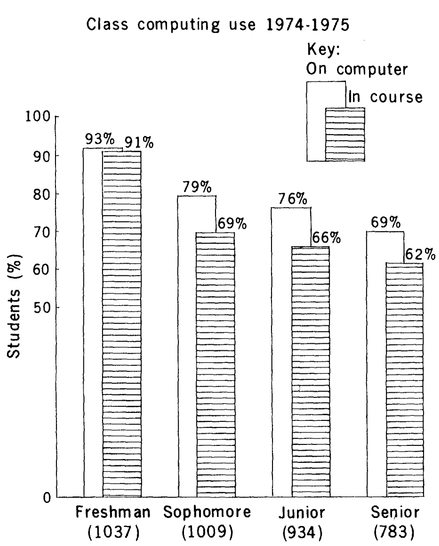
A new instructor at Dartmouth will find computing all around him (*12*). At a faculty meeting about half of those attending will have used computing and almost one-quarter will have included it in their teaching in the last year. The instructor will find the cliché about the older member being unversed in the new techniques completely untrue; gray hair will reveal nothing about computer use.

Table 1 shows the instructor how important the new tool is in each academic division. After he examines the data, he may well conclude that only if he is in the humanities can he put off learning about how computing works at the college. If he decides to learn, it will be under ideal conditions (*2*, p. 39): "A nearby console and simple programming languages . . . make it especially easy for a faculty member to learn and to experiment with the new tool in spare moments and in private."

Colleagues will report how computing affects their courses. "Design is taking a simple idea and through repetition, creating something organic, complex," an artist-teacher says; "by doing a computer project, a student will better grasp that idea." The engineer shrugs, "Computing is no big deal. I assume they all know how to write a program when they walk through the door. We use the computer as a tool." "It is a qualitatively different course from that at other universities," the geologist insists, "I could not teach it without the computer." A sociologist explains, "Computing, and in particular IMPRESS, has changed the way I teach the course. Now the student takes his theory and confronts it with the actual survey data."

## Course Titles

The following list shows the titles (144) of the courses (184) at Dartmouth in which computing was used during the year from summer 1974 to spring 1975. Some titles were taught in several sections or in several terms, so that the number of courses is larger than the number of titles.



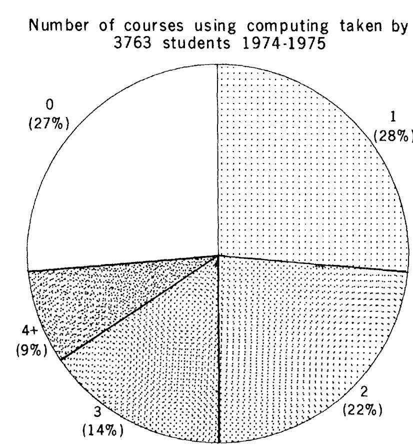




Fig. 4 (left). Students use computing through all 4 years of college. Both the portion of the class that signs on the computer (plain bar) and the portion that enrolls in courses where computing is used (shaded bar) exceed 60 percent for all classes. Freshmen use reflects the high enrollment in elementary mathematics courses, where computer work is a course requirement. Extracurricular computing is reflected in the dominance of those on computer over those in courses. The actual number of students in each class is enclosed in parentheses. Fig. 5 (right). Computing goes deep into students' courses. Half of the students enrolled in one or two courses which used computing during the last year. Almost one-quarter enrolled in three or more. While students could take as many as 12 courses in the 4-term year, most take 9. Two students enrolled in 8 courses where computer programs were used. This figure represents the experience of only one of a student's 4 years of college.

*Anthropology*
- Introduction to Anthropology
- Introduction to Biological Anthropology
- Ethnography
- Folklore

*Art*
- Basic Design

*Biology*
- Life Science
- Comparative Animal Physiology
- Endocrinology
- Biochemistry
- Seminar in General Biology

*Chemistry*
- General Chemistry I
- General Chemistry II
- General Chemistry III
- Physical Chemistry I: Chemical Thermodynamics
- Physical Chemistry II: Chemical Dynamics
- Topics in Advanced Organic Chemistry

*Classics*
- Greek Archeology: Classical and Hellenistic
- Introductory Latin
- Cicero

*Earth Sciences*
- Elementary Oceanography
- Marine Geology
- Geochemistry
- Tectonics

*Economics*
- Economics of the Stock Market
- Macroeconomics
- Macroeconomics Fluctuation and Growth
- Mathematical Economics

*Education*
- Independent Study in Education

*Engineering Sciences*
- Surveying
- Systems I
- Principles of Systems Dynamics
- Distributed Systems and Fields
- Solid Mechanics
- Systems II
- The Application of Optimization to Environmental Management
- Fluid Dynamics
- Electronics II
- Computing Methods in Science and Engineering
- Urban Transportation
- Electronics III
- Semiconductor Theory Devices I
- Heat, Mass and Momentum Transfer
- Design and Analysis of Experiments
- Intermediate Fluid Dynamics
- Introduction to Two-Phase Flow
- Independent Study (Computing)

*Environmental Science*
- Introduction to Modeling Environmental Systems
- Environmental Policy Formation
- Human Population Dynamics

*Geography*
- Introduction to Human Geography
- Freshman Seminar in Geography
- Freshman Seminar in Geography: Viewpoints on the Third World
- Geography of Food and Hunger
- Spatial Analysis
- Remote Sensing
- Geographic Methods
- Field Research
- Introduction to Advanced Geographic Study
- Urban Geography
- Urban-Regional Simulation and Games
- Agricultural Land Use and Agribusiness
- Seminar in Remote Sensing

*German*
- Introductory German

*Government*
- International Politics
- American State Politics
- Politics and Economics of Government Budgeting
- Political Behavior
- Public Opinion and Voting Behavior—The 1972 Presidential Election
- Seminar in Politics and Economics of Government Budgeting
- Politics and Biology
- The Nature of Political Enquiry

*History*
- Urban History
- Comparative History of Black and White

*Mathematics*
- Elementary Functions
- Calculus and Differential Equations
- Advanced Placement Calculus
- Introduction to Finite Mathematics
- Introduction to Calculus: Honors Section
- Calculus and Differential Equations: Honors Section
- Advanced Placement Calculus: Honors Section
- Elementary Statistics
- Linear Algebra and Calculus of Several Variables
- The Role of the Computer Outside the Sciences
- Linear Algebra and Calculus of Several Variables: Honors Section
- Discrete Probability
- Functions of Several Variables
- Introduction to Numerical Analysis
- Introduction to Computer Science
- Mathematical Models in the Social Sciences
- Probability and Statistical Inference
- Functions of a Complex Variable
- Fundamentals of Systems Programming
- Information Structures
- Logic: Honors Section
- Graph Theory

*Mathematics-Social Sciences*
- Analysis of Social Networks
- Data Analysis

*Music*
- Listening, Composing, Performing
- Introduction to Music Theory
- Theory I
- Theory II
- Introduction to the Composition of Electronic Music
- Theory III

*Philosophy*
- Logic and Language

*Physics and Astronomy*
- Cosmology
- Introduction to Astrophysics
- Galactic Structure and Dynamics
- General Physics I
- General Physics II
- Freshman Seminar in Physics
- Introductory Physics I
- Advanced Placement Physics: Mechanics, Electricity and Magnetism
- Advanced Placement Physics: Waves, Modern Physics, Thermodynamics
- Modern Physics and the Construction of Reality
- Electricity and Magnetism I
- Electricity and Magnetism II
- Mechanics
- Methods of Theoretical Physics
- Optics
- Thermodynamics
- Quantum Mechanics I
- Solid State Physics I
- Advanced Laboratory
- Special Topics in Physics
- General Relativity and Cosmology

*Psychology*
- Introductory Psychology
- Social Psychology
- Experimental Study of Perception
- Experimental Study of Social Behavior
- Experimental Study of Cognition
- The Teaching-Learning Process in the University
- Environmental Psychology
- Seminar in Pattern Recognition
- Independent Research
- Statistics in Psychology
- Advanced Issues in Statistics and Design

*Sociology*
- Human Society
- Methods of Sociological Inquiry
- Technology Work and Society
- Bureaucracy in Contemporary Society
- The Family as a Group and an Institution
- Urban Planning
- The Analysis of Continuous Social Science Data
- Reading Course in Cross Cultural Analysis

### Computing and the Student

The new student may have the advantage over his new instructor: studies have shown that the student chose to come to Dartmouth in part because of its computing facilities. The data in Fig. 4 show that computing is used heavily by all four classes. While usage declines from freshman to senior year, all classes have at least 69 percent of their members signing on the computer during the year. As mentioned earlier, this breakdown by class appears to be relatively constant over time. The high participation of the freshman class is probably due to the large number enrolled in the freshman mathematics program, where the short introduction to programming is part of the course. The clear and shaded bars in Fig. 4 show that students in the upper three classes continue to use the computer heavily and to enroll in courses where computing is used.

In general a student who is enrolled in a course where computing is used actually does sign on the Dartmouth time-sharing system. Despite some use of small stand-alone computers and off-campus computers, 90 percent of the students in computing classes work on the local system. The shaded bars and the clear bars in Fig. 4 overlap in truth as well as in representation.

The shading in Figs. 1 and 4 could

represent a thin veneer of students who take only one computing course each year, but Fig. 5 reveals that computing among the students is not merely broad, it is deep. In a school where most students take nine courses in an academic year, half take one or two courses with computing and 23 percent take three or more. Two students actually enrolled in eight. It is important to realize that Fig. 5 represents only one of the 4 years a student will attend college. In 4 years he can expect to enroll in six courses where computing is used (*13*).

So, the new student will expect to see computer programs used early and frequently in his liberal arts education. He will expect to learn how to write a computer program and then apply this skill in his courses.

### Computing in Courses

From summer 1974 through spring 1975, 1500 courses were taught at Dartmouth. Of these, 184 (12 percent) are known to have used computing. As shown in Fig. 1, almost one-quarter of the faculty and three-quarters of the undergraduates are involved in these courses. For each course the instructor was asked the following questions:

1) Do students in this course write programs of their own?

2) Do your students ever run a canned program?

3) What is the single most important benefit of computing in the course?

The answers to these questions, broken down by division, are collected in Table 2. The first striking feature is that the large number of science courses is almost balanced by the number of social science and humanities courses together. It is interesting to note that only five of the 96 science courses are in computer science. Table 2 also shows how important the ability to write a program is to a student in the sciences. If he enrolls in a course where computer programs are used, there will almost always be an occasion for him to write a program. Surprisingly, this situation also holds in nearly half of the social science courses as well. In only two of the humanities courses were students writing computer programs.

The uses of a computer program vary considerably. Sometimes the teacher's aim is to familiarize the students with a quantitative procedure by requiring them to formalize the procedure in a computer program. Or the purpose is to enable them to develop an intuition about the procedure by modifying the program in a number of ways. Other student uses of computer programs include finding finite approximations for systems with no analytical solutions, obtaining quick answers to an otherwise intractable series of calculations, or repeating a simple calculation over and over on an enormous quantity of data. Occasionally a complicated model is best explained through a computer simulation that each student writes for himself.

No matter what the academic discipline, a student in a class with computer programs can expect to spend some time working with someone else's program. These canned programs vary considerably in content and use. In the sciences, canned programs are frequently computer library subroutines that enable users to extend their own programs to plot data. Such routines should be viewed as extensions of writing a program rather than as passively used canned programs. This view has led to plans to incorporate elementary plotting commands in the next version of the computer language Basic (*14*). This action will substantially reduce the use of canned programs in science courses. However, some canned programs will continue to be used to plot parametric representations of functions in mathematics, to do linear regressions on laboratory data in chemistry, and to simulate the estrous cycle's hormone variation in elementary biology.

The canned programs in the social sciences are of three major kinds: a large interactive system that allows one to examine the results of surveys, a library of statistical routines, and a variety of games. The survey analysis program IMPRESS (*15*) is the program most used in classes in sociology and government. Its use has extended into psychology, anthropology, economics, and even history. The surveys available range from presidential election surveys to cross-cultural ethnographic files, but classes and individuals also enter the findings of their own surveys to analyze the results. (Several of the results in this article first appeared as IMPRESS cross tabulations of data from the course interviews.) The statistics programs in the public library are frequently employed in the more quantitative courses in sociology, psychology, government, and economics. The one most cited performs multiple linear regressions.

In both government and geography courses several games are played on the computer. A class studying the rice agriculture of Southeast Asia plays a game where the student tries to grow a good crop while being threatened by pest, fire, and flood. The average student plays the game 20 times and one student played it 150 times. A game becomes an experiment when a student in experimental psychology writes a program that tells the computer how to flash patterns of letters at a test subject for small intervals of time. Such experiments sometimes yield new insights into cognitive psychology, and they almost always teach something about the design of experiments (which is the subject of the course).

In the humanities at Dartmouth, while an art class does computer projects, the major activity centers on drill programs in music, foreign language, and philosophy. Music programs are of two kinds: the first refines a student's ability to listen and to pick out musical structures. The second, and more creative, program allows the student to compose a piece of music which is immediately played back on a synthesizer and can then be altered and amended by the student until he is pleased with the results. The foreign language drills in German and Latin are options that students can use to drill themselves in vocabulary. In the logic courses in philosophy and mathematics, Bertie, a program named after Bertrand Russell, checks a student's proof of theorems in sentential and predicate logic (*7*).

### Strengthened Bond Between Student and Subject

Because computer programs can do so many different things and affect courses in so many ways, the instructors were asked to pinpoint the single most important benefit to each course. Behind most descriptions (82 percent) was the assertion that computer programs had allowed the student to become more involved in the subject and consequently learn it better. Computing was described in terms such as, "concrete expression of a theoretical concept," where the student could, "experiment with," "test hypotheses," "play with," "develop ideas," "explore," and "confront the theory." Student interest was enhanced because they were able to do complex calculations with "real-world" numbers. Large, unwieldy collections of data in the social sciences could be "reduced," "manipulated," "handled," "analyzed," and "examined" by the students themselves.

The strengthened bond between the student and the subject represents a qualitative change in courses. It occurred most frequently in the sciences and least frequently in the humanities. It correlates strongly with whether or not a student has an opportunity to write his own programs (*16*). If there were a method of determining which canned programs required creative responses from students, they too would probably correlate highly with this qualitative improvement that instructors see.

The important point is that when students creatively interact with a computer, either by writing a program or imaginatively using someone else's program, they can, and do, become more involved with the subject of the course.

The faculty felt that computing made 90 percent of the courses "better." Their estimate of the importance of this work is summarized by their responses to the question, "How would you characterize the role of computing in the structure of the course; is it integral, supplemental, or incidental?" In 14 percent of the courses the role of computing was characterized as incidental, in 39 percent as supplemental, and in 47 percent as integral.

Table 2. Computing in courses at Dartmouth. The number of courses where computing is used is split almost evenly between science and nonscience. Many courses allow a student to write a computer program and almost all run canned programs. The instructor's description of the primary benefit of computing as a qualitative improvement in the course is strongly related to whether or not the students had the occasion to write programs. The "yes" responses represented in the last three columns are to the questions: "Do students in this course write programs of their own?," "Do your students ever run a canned program?," and "What is the single most important benefit of computing in the course?"

| Group | Courses where computing is used (No.) | Student writes own program (%) | Student uses canned program (%) | Benefit was qualitative change (%) |
|---|---|---|---|---|
| Humanities | 22 | 9 | 91 | 18 |
| Social sciences | 66 | 42 | 98 | 80 |
| Sciences | 96 | 91 | 78 | 98 |
| College | 184 | 64 | 86 | 82 |

## Computing Literacy

The widespread use of computer programs at Dartmouth is largely the result of a self-teaching time-sharing system and the organic growth of applications to the real academic needs of students and faculty. Only five courses at Dartmouth have to do specifically with computer science, yet the broad use of computing flourishes because an adequate system is freely available to the students and faculty.

It is clear that early introduction to computing and widespread application to course work creates a pool of individuals able to write a computer program. Within that pool are a number who are not only willing, but eager, to write programs. Several instructors commented during the interviews that a student had come up with the original idea of applying computing to the course. Not only did the student serve as a rich source of new ideas, he was also the one who worked with the instructor to implement the idea.

The social science survey analysis system IMPRESS was written by students. Several of the language drills were programmed by students. The systems for music training and music composition were written by an engineering major working with a professor of music. The proof-checking program in the philosophy course was a student-teacher collaboration. In geography, the regional development games were either written or completely overhauled by students. These systems represent the bulk of the canned programs used in courses where the students did not write their own. So even where students do not write a program, they rely on others who do (*17*).

This creative pool of student talent flows into almost every course at the college. As new ideas appear, not only the instructors, but also their students, are on the watch for an interesting way to approach these ideas through computing. The pool of student talent ensures that computing applications will evolve as the courses evolve.

Since most students are acquainted with writing a computer program, they are not shy about running someone else's program, be it a linear regression or an urban game. They are also quick to notice shortcomings in canned programs and sometimes offer improved versions of their own. Because of the widespread use of elementary computing skill, there should be an appropriate term for this skill. It should suggest an acquaintance with the rudiments of computer programming, much as the term literacy connotes a familiarity with the fundamentals of reading and writing, and it should have a precise definition that all can agree on.

It is reasonable to suggest that a person who has written a computer program should be called *literate in computing*. This is an extremely elementary definition. Literacy is not fluency. Few of the people said to be literate around the world are capable of composing fine essays. They can, however, jot down grocery lists to do their shopping. So with computing. One who has written a program has grasped the idea of how a machine accomplishes a task through a step-by-step procedure, but does not necessarily have the facility to compose elaborate computer programs.

One advantage of this definition is that it allows one to measure the *computing literacy rate* of students and faculty. At Dartmouth, the class of 1975 at graduation contained 455 students (70 percent) who had been in a mathematics course where writing a computer program was required. These who had actually signed on the computer numbered 725 (93 percent). So one can say that the computing literacy rate is at least 70 percent and probably higher. The survey results in Table 1 estimate the faculty computing literacy rate to be 45 percent.

## Summary

Ten years ago one could have argued over whether undergraduates would really have much use for computing in their liberal arts studies. One could have wondered whether there were many subjects where a conscientious instructor could make significant use of a computer program. One could scoff at the possibility that a liberal arts college would regularly graduate classes where more than 90 percent of its members had used a computer. One could have raised a skeptical eyebrow at anyone rash enough to suggest that a person interested in a liberal education should learn how to write a computer program.

Today the evidence has done away with these arguments. At Dartmouth, the ability to use a computer program and, more important, the ability to write one are widespread. Computing literacy is high. Students expect to encounter many courses where computing is used during their 4 years in college. Faculty members are mature users and apply computing to a wide variety of courses. They have seen how a computer program can strengthen the bond between the student and the subject by providing a new way to explore the subject. This strengthened bond represents a qualitative improvement found in most of the courses which use computer programs. The faculty confirm the significance of this activity when they call computing integral to their courses.

Ten years' experience at Dartmouth demonstrates that an easy-to-use computer system open to the whole campus will be widely used in undergraduate instruction. It should be no surprise that a college full of this kind of computing activity comes to regard its computer center much the way it regards the library. To make use of its services is "no big deal," but to do without them would be "unthinkable."

### References and Notes


1. For a discussion of some trends in networks, see M. Greenberger, J. Aronofsky, J. L. McKenny, W. F. Massey, Eds., *Networks for Research and Education: Sharing Computer and Information Resources Nationwide* (MIT Press, Cambridge, Mass., 19[illegible] *Science* **182**, 29 (19[illegible] R. W. Cornew and P. W. Morse, *ibid.* **189**, 523 (1975).
2. The President's Science Advisory Committee, *Computers in Higher Education* (The White House, Washington, D.C., February 1967).
3. *Kiewit Comments* **7** (No. 12) (1974); *ibid.* **8** (No. 11) (1975).
4. J. G. Kemeny and T. E. Kurtz, *Science* **162**, 223 (1968).

A. W. Luehrmann and J. M. Nevison, *ibid.* **184**, 957 (1974).

6. The cost of computing per student per course was under $30 for the academic year 1974–1975.
7. Further details may be found in J. M. Nevison, *Computing as a Matter of Course: The Instructional Use of Computers at Dartmouth College* (Kiewit Computation Center, Dartmouth College, Hanover, N.H., 1976).
8. This is not unlike the growth recommended in R. Levien *et al.*, *The Emerging Technology, Instructional Uses of the Computers in Higher Education* (McGraw-Hill, New York, 1972).
9. *Biennial Report* (Kiewit Computation Center, Dartmouth College, Hanover, N.H., 1973), p. 12.
10. The distributions illustrated in Fig. 3 are the "yes" responses. Cross tabulations of "yes" and "no" responses against the respondents' ages (young, 25 to 39; old, 40 to 68) produced chi-square tests that support the claim that age is not significantly related to computer use. The idea for the box and whisker plots came from J. W. Tukey, *Exploratory Data Analysis* (Addison-Wesley, Reading, Mass., in press).
11. For an excellent introduction to the current variety of uses in higher education, see C. Mosmann, *Academic Computers in Service* (Jossey-Bass, San Francisco, 1973).
12. Masculine pronouns are used in this article only for convenience; the individuals referred to should be understood to be of either sex.
13. Figure 5 is based on data showing that the number of computing courses that students take obeys a Poisson probability law at a mean rate of 1.5 courses per student per year.
14. *Kiewit Comments* **7** (No. 11) (1974), pp. 1–3.
15. IMPRESS is an acronym for interdisciplinary machine processing for research and education in the social sciences. It is described in *The IMPRESS Primer* (Project IMPRESS, Dartmouth College, Hanover, N.H., 1971) and in *The IMPRESS Manual* (Project IMPRESS, Dartmouth College, Hanover, N.H., 1972).
16. A cross tabulation between whether or not some students in a course wrote their own computer programs and whether or not the instructor said the single most important benefit was a qualitative change in the course showed a chi-square value that was significant at the .001 level.
17. The most outstanding example of this reliance is the operating system itself, which was written largely by undergraduates. See Kemeney and Kurtz (*4*).



18. I thank R. Sokol for his essential advice on survey design.


# Science in a Political Context: One View by a Politician


James W. Symington


The December 1934 Pittsburgh meeting of the AAAS marked a significant change in the way many scientists looked at working with government. At that time, the prevailing attitudes among scientists about the relation of government to science were characterized by fears of political control, should government provide funding support. Nevertheless, the new AAAS president, Karl T. Compton, had proposed to President Roosevelt in 1934, a "Program for Putting Science to Work." The ultimate value of Compton's proposal and his advocacy role was the influence on two momentous political decisions made during the Roosevelt presidency: the extension of the government's responsibility for science beyond its own establishment and the coupling of science and government to serve national purposes. Several decades ago, both of these were revolutionary concepts.

Although Compton's *specific* proposal was not approved by President Roosevelt, federal science budgets were increased, universities began to receive government support, and there emerged a growing consensus in the 1930's among some scientists and politicians that they should work more closely together. This latter development was no small achievement—and I need not recount here how vital to our national security such relationships became as the clouds of World War II broke. President Roosevelt had already developed high respect for scientists, and he entrusted great responsibilities to them in the war effort after bringing them into the highest councils of government.

It is significant that the science and public policy questions that began to emerge in the 1930's have a very modern appearance. Several of these questions dealt with (i) recommendations to establish national policy with respect to science; (ii) suggestions that the United States participate more fully in the international scientific community and that it draw to a greater extent on the world reservoir of knowledge; (iii) attempts to counteract the frugality of Congress with respect to science; (iv) advice designed to eliminate duplication or improve intragovernmental coordination of scientific activities; and (v) suggestions intended to improve and increase the basic research activities of government agencies (*1*, *2*).

For the past decade, the Committee on Science and Technology has devoted much of its attention to these kinds of questions. Thus, the pessimist would say that we have not made much progress in 40 years. However, I think that continuing consideration of these questions points to the enduring nature of a number of large issues in science policy. Some may never be settled. In each generation we must deal with these issues by taking actions that are appropriate to the special circumstances and problems of the times.

## Federal Role in Support of Science and Technology

Among the policy issues in a continual state of flux is the federal role in the support of science and technology. Some support has been provided since the beginning of our nation; however, the federal role changed dramatically as a result of World War II. For more than 25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