Conclusion

Our discussion has of necessity been limited to the research process alone. However, we might have pursued the evolution of new science beyond research into the engineering and development processes, and cited counterparts of the same revolutionary trends and effects. Even within research, we haven't even alluded to whole broad areas of physics, biology, materials science, mathematics, economics and systems science from which could have been drawn other striking instances of revolutionary computer impact through enhanced mastery of complexity. Our case has been understated.

What of the future? The revolution, well begun, has by no means run its course. While no one can foretell its form, some of the propelling forces are clear. The hardware costs of computing power continue to drop by two orders of magnitude per decade. Great strides are being made in facilitating and automating the production of software for complex procedures. Methodology is evolving for the aggregation of numerous, specialized processing units into distributed, federated entities with new orders of capabilities. And, at a most fundamental level, new bridges of common technique, understanding and philosophy are abuilding between and among the diverse disciplines—deriving from a shared common language for discourse on complexity. Computerese is the new *lingua franca* for science.

References and Notes

1. W. O. Baker, *Daedalus* **99**, 1088 (1970).
2. R. A. Kennedy, in *Industrial Information Systems*, E. B. Jackson and R. L. Jackson, Eds. (Dowden, Hutchinson and Ross, Stroudsburg, Pa., in press).
3. W. S. Brown, J. R. Pierce, J. F. Traub, *Science* **158**, 1153 (1967).
4. M. V. Mathews, *IRE Trans. Inform. Theory* **IT-5**, 129 (1959).
5. S. P. Morgan, *Bell Labs Record* **51**, 194 (1973).
6. J. L. Flanagan, *Proc. IEEE* **64**, 405 (1976).
7. See, for example, K. B. McAfee and R. Gnanadesikan, *A.I.Ch.E. Air Pollution Symp. Series*, in press.
8. D. Edelson, *J. Comp. Phys.* **11**, 455 (1973).
9. W. S. Cleveland, T. E. Graedel, B. Kleiner, J. L. Warner, *Science* **186**, 1037 (1974).
10. R. N. Shepard, A. K. Romney, S. B. Nerlove, *Multidimensional Scaling: Theory and Applications in the Behavioral Sciences*, (Seminar Press, New York, 1972), vols. 1 and 2.
11. U. Neisser, *Cognitive Psychology* (Appleton-Century-Crofts, New York, 1967).
12. A. Newell and H. A. Simon, *Human Problem Solving* (Prentice-Hall, Englewood Cliffs, N.J., 1972).
13. S. Sternberg, *American Scientist* **57**, 421 (1969).
14. D. E. Knuth, *Science* **194**, 1235 (1976).
15. B. W. Kernighan, *Software—Pract. Exper.* **5**, 395 (1975).
16. B. G. Ryder, *ibid.* **4**, 359 (1974).
17. D. M. Ritchie and K. Thompson, *Commun. ACM* **17**, 365 (1974).

Tutored Videotape Instruction: A New Use of Electronics Media in Education

J. F. Gibbons, W. R. Kincheloe, K. S. Down

In the early 1920's, shortly after radio broadcasting was proved to be economically feasible, Robert Hutchins is said to have predicted that this new technology would undoubtedly have a dramatic impact on education. Subsequent events have shown that his assessment of the educational potential of radio was probably correct but, for a variety of reasons, the potential did not materialize. In the early 1950's instructional television was introduced with a similar fanfare. However, with a few notable exceptions, its potential also failed to materialize. It seems that more recent innovations such as computer-aided instruction and satellite-based educational delivery may come to a similar fate. Why is it that these technological aids to education seldom seem to live up to their potential?

There is of course a different set of reasons in each case, though inconstant financing and the competition with commercial interests are surely among the most pervasive. However, important as these factors are, there seems to be a still more basic problem. The proponents of media-based education describe this problem as a failure of the educational establishment to involve itself seriously with instructional technology. As a result, they say, the changes in the design of the educational system that must be made before instructional technologies can be used effectively have not been forthcoming. This is a valid criticism. However, the educational establishment makes a counterargument that is also true: The devices of instructional technology are too inflexible. Effective classroom teachers regularly capitalize on unexpected, unplanned opportunities for the achievement of specific goals. As Jackson (*1*) says, "Stray thoughts, sudden insights, meandering digressions and other unpredicted events constantly ruffle the smoothness of the instructional dialogue. In most classrooms, as every teacher knows, the path of educational progress could be more easily traced by a butterfly than by a bullet." Jackson concludes from this that education is best served by tools that can be readily adapted to a wide variety of educational tasks with a minimum of advance planning. Compared to most electronics media, blackboards and books provide at low cost an impressive degree of flexibility. Furthermore, after honest efforts to use electronics media over an extended period of time, many teachers have been unable to see a clear improvement in learning. Hence, electronics media are generally judged by teachers to be inappropriate educational tools for most circumstances.

Tutored Videotape Instruction

If we accept these criticisms as valid, we are led to seek out ways of using those media that will have the desired flexibility without requiring a major change in teaching styles, and to apply them to situations where the changes in the educational system that are necessary to accommodate them can be easily

---

Dr. Gibbons is professor and Dr. Kincheloe is adjunct professor of electrical engineering, and Mr. Down is assistant dean of engineering at the Stanford University, Stanford, California 94305.

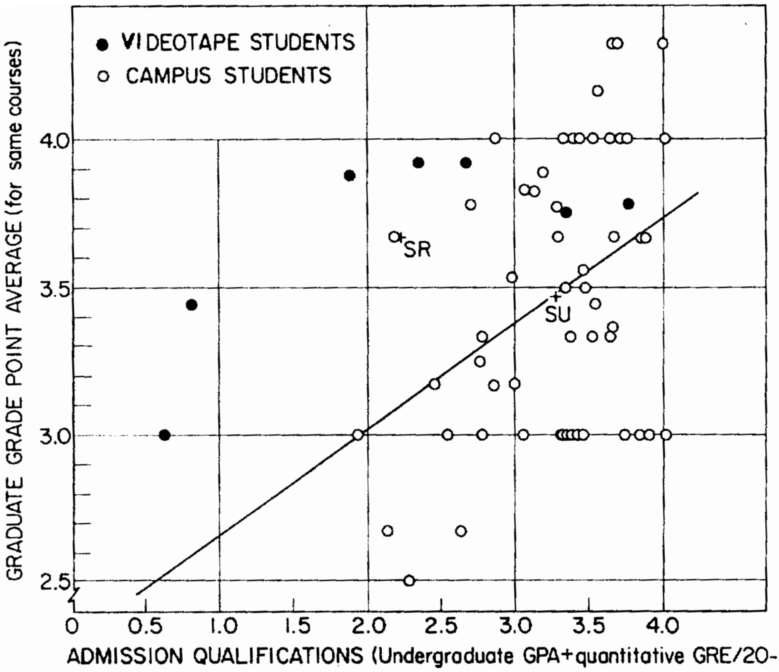

Fig. 1. Results of tutored videotape instruction experiment (October 1973 to March 1974).

made. In this article we describe a new technique for using videotaped educational materials that seems to meet these criteria. The method makes use of unrehearsed, unedited videotapes of regular classroom courses, which can be produced at very low cost. The videotapes are used for the instruction of small groups of students (typically 3 to 10) who are assisted by paraprofessional tutors as they watch the tape. For this reason, the method is called Tutored Videotape Instruction (TVI).

The TVI method was originally developed to provide course work in science and engineering to off-campus graduate students enrolled at Stanford University. It is based on the common-sense notion that students can learn more from a lecture if they are free to interrupt it at places where they need more discussion or explanation of a point or concept. Experience over the past 3 years shows that students learn best when the videotaped lectures are stopped frequently (for example, every 5 to 10 minutes, for periods of 3 to 5 minutes). Interactions of such frequency and duration are, of course, impracticable in a conventional classroom situation. Also, TVI is most effective when a small group of students and the tutor watch the tape together. It is less effective for a single student, with or without a tutor.

The TVI technique responds to the educational needs of the students by combining the positive features of lectures with those of small group discussions. The lectures provide for depth and continuity in the subject matter, while the tutorial discussions afford a means of making the lectures respond to individual needs and differences. Students watching the videotaped lectures feel free to ask questions of both the tutor and each other, and to make spontaneous comments about points of interest. In addition, the TVI students hear the comments that were made and the questions that were asked in the classroom at the time the videotape was recorded, and thus profit from those exchanges as well. In effect, the TVI format permits the students and the tutor to manage the lecture themselves and thereby create an intellectually stimulating environment which enhances learning and creates a positive attitude toward the subject.

Although the program to be described relies heavily on the use of video technology, that is probably not its most distinctive feature. Rather, the technology permits us to concentrate attention on some of the most important parameters in the learning process and to begin to understand their effects more precisely. What has been found seems to be applicable in a wide variety of circumstances. It extends well beyond university lecture courses and is in some ways independent of whether or not technological aids are used in the instruction process.

The program was designed to utilize insofar as possible the experience which has been gained over the past two decades concerning the question of how technology can be used most successfully in education. An attempt to summarize this experience led one of us to develop a set of guidelines that could assist educators in planning for the appropriate use of technology in education (2). Because those guidelines form the basis of the program to be discussed, it is useful to begin with a brief discussion of them.

Guidelines for the Application of Technology to Education

Current interest in the use of technological aids to education (particularly television) stems from the late 1940's and early 1950's when, following the widespread development of commercial television, the Ford Foundation and later the federal government funded a variety of experiments to study the possible impact of television on the educational process. These experiments included a complete range of educational institutions from elementary school to university, and took as their major emphasis the question of whether students could learn as well from television as from conventional classroom teaching. Surveying the results of 421 experiments carried out from 1950 to 1960, Chu and Schramm (3) concluded that, across all grade levels from kindergarten through a baccalaureate degree, and for essentially all types of subject matter, students could learn as well from television as from conventional instruction.

Viewed in its most positive light, this result suggests that access to education can be expanded substantially by communications technology, and indeed this policy has been urged by educational study groups and implemented by both private and public educational institutions for some time, and at substantial expense. However, the educational effectiveness of classroom instruction is itself a matter of increasing concern, and in this light a finding of "no significant difference in effect between television instruction and the regular classroom" does not provide a forceful stimulus to promote the application of communications technology to educational problems.

This raises the question of whether educational technology has ever established a clear-cut superiority over in-class instruction. From a comparison of some of the most successful ventures in educational technology (such as Sesame Street, Chicago City TV College, the Open University in Britain, the Australian School of the Air, and the Bavarian Telecollege) with some of the least successful ventures, we attempted to abstract a set of guidelines that would describe the conditions that seem most likely to ensure a successful application of technology to education. These guidelines, while they may need further refinement and modification, do provide a useful starting point for designing new programs.

The guidelines are as follows:

1) The educational program should be planned for a specific audience.

2) Specific educational objectives that are relevant to the needs and interests of the audience should be clearly defined.

3) Technologies should be chosen in terms of the topic to be presented. Frequently, different technologies are used to present different parts of a course, the choice being determined from a consideration of which technology is most effective for the material being presented. It is desirable (though also expensive) to use both knowledge and media specialists to prepare and produce the programs.

4) Educators who have a clear interest in learning and using the instructional characteristics of various media should be selected and trained.

5) Clear and careful provision should be made for personal interaction, especially among the students.

6) Evaluation and feedback over a period of months or years should be used to monitor the educational effectiveness of the program, and the instructional materials and methods should be changed accordingly.

From the standpoint of educational effectiveness, the guideline that is perhaps most frequently overlooked is the one relating to personal interaction, especially where the use of television is concerned. Television (including lectures that are videotaped for subsequent playback) is most frequently used as a direct substitute for live lectures in large classes or as a means for individuals to view lectures or programs at sites that are remote from the point of origin. These applications are developed primarily to solve problems of cost and access, the assumption being made that courses delivered by television will be as effective as conventional education. However, the experiments that led to this conclusion tested only factual information gained over a relatively brief period. Furthermore, these experiments identified some characteristic weaknesses of television as an educational medium. In particular, as noted by Schramm (*4*), television does not stop to answer questions; it does not readily permit classroom discussion; it is an inefficient medium for conducting drill; it does not adjust very well to individual differences; and it tends to encourage a passive form of learning.

These are very serious weaknesses. They can be reduced to some degree by using radio talkback to connect remote sites to the television classroom (*5*), or by establishing a regular telephone contact between students and faculty, as has been done by the Chicago TV College and others. However, these techniques for promoting student-faculty interaction do not really remedy the major weaknesses described above. It is critically important for students to be able to stop a lecture or a program when they have questions, and it is highly desirable for it to remain stopped long enough for the question to be clearly answered. It is also highly desirable that the answers to the most important questions be developed as a result of active discussion within a small group of students. Finally, it is important that questions and discussions be used to determine background deficiencies of individual students, so that remedial action can be taken.

The major weaknesses of live television (including videotapes that are simply replayed from start to finish) are related to the fact that it cannot provide the quality of personal interaction that is available in a good classroom. The TVI intellectual community, consisting of a small group of students, an on-site paraprofessional tutor, and a course faculty member, was invented in an attempt to circumvent these deficiencies. What we seek to do is to provide small groups of students with the high-quality personal interaction that they need in order to learn effectively. What we have found is that TVI can provide a means of achieving this goal.

Experiments with TVI

We have carried out a number of experiments to evaluate the educational effectiveness of the TVI format. All the experiments to be discussed have been concerned with the delivery of engineering and science courses where the objectivity of the material makes it relatively easy to measure the effectiveness of the method. We believe the method can be extended to a much larger range of subjects and audiences, but there are insufficient data available at present to permit us to define this range of applications with any accuracy. Our description of experiments is therefore intended primarily to provide some general ideas about how the TVI format can be set up and evaluated.

The TVI technique was originally conceived as a means of providing courses to off-campus engineering students employed at a Hewlett-Packard (HP) plant in Santa Rosa, California, about 100 miles north of Stanford. The HP management wished to provide the same educational opportunities to these students as were available to HP employees (and those of other companies) at plants near Stanford where engineering courses given on campus are televised to plants within a 50-mile radius of the university by the Stanford Instructional Television Fixed Service (ITFS) network. The ITFS students also have an audio talkback connection that permits them to ask questions of the instructor while the class is in progress.

Since the courses of interest were already being televised, it was a simple matter to videotape the classes live with no further production requirements. It should be noted that an operating TV system is not a prerequisite for the TVI technique, though it was very helpful in this case because it both facilitated the initial experiments and made possible a thorough comparison between the regular TV students and the videotape students.

It was intended from the outset that satisfactory performance in the courses would result in credit toward a master's degree in electrical engineering from Stanford. Therefore, the Santa Rosa students were required to complete the same homework as students on campus, all their papers being graded by the same teaching assistant who graded the papers of the on-campus and regular TV students, and the off-campus students were required to come to the campus to take the same examinations as the on-campus students.

Program design for the Santa Rosa experiment. The main features of the program developed for the Santa Rosa experiment can be described in terms of the guidelines listed above.

1) The audience consists of industrially based students carrying full-time job responsibilities. In some cases the students were studying for a master's

degree before they were moved to Santa Rosa and had academic qualifications that were essentially identical to those of on-campus students, but students at Santa Rosa whose academic credentials were known to be inadequate for admission to the Stanford graduate school were also included.

2) In defining the educational objectives, we knew that the students were interested in graduate training leading to a master's degree. A clearly important factor in their success was that their employer shared this objective, in both its financial and academic aspects.

3) The technology used, half-inch reel-to-reel videotapes, was chosen to permit the clear reconstruction of a given TV frame at the remote sites. The videotapes were of live classes made by a trained student production staff as the class was being conducted. The classroom modifications that are necessary for this purpose are described by Pettit and Grace (5). Basically, the studio classrooms are organized to interfere as little as possible with the teaching styles and preferences of the instructors.

The videotapes are mailed to Santa Rosa along with class notes, homework assignments, and other materials that are handed out to the on-campus students. The tapes and homework are returned to Stanford in approximately 1 week. When necessary, the TVI tutors telephone the on-campus faculty after the videotapes have been watched to discuss problems and obtain supplementary material.

4) The educational staff whose courses are to be televised are given a brief training session to acquaint them with the capabilities of the television network and to offer suggestions concerning how these capabilities can be used effectively (how to organize blackboard space, use of a desk pad as an alternative to the blackboard, preparation of demonstrations, and so on).

In addition, Stanford staff members who are responsible for the TVI program visit each site to choose the tutors (from among the company's staff) and to instruct them in the use of the videotape as an educational medium. An alternative that is now being explored is to use as tutors staff members from local educational institutions who have indicated an interest in the program.

In most instances, the tutors are practicing engineers without prior experience in teaching. They are chosen primarily on the basis of two criteria: (i) a sensitivity to students and an ability to draw them into a fruitful discussion of issues, and (ii) a personal interest in reviewing the subject to be presented. Other criteria, such as recent exposure to the course with evidence of high-quality performance, have been found to be less important.

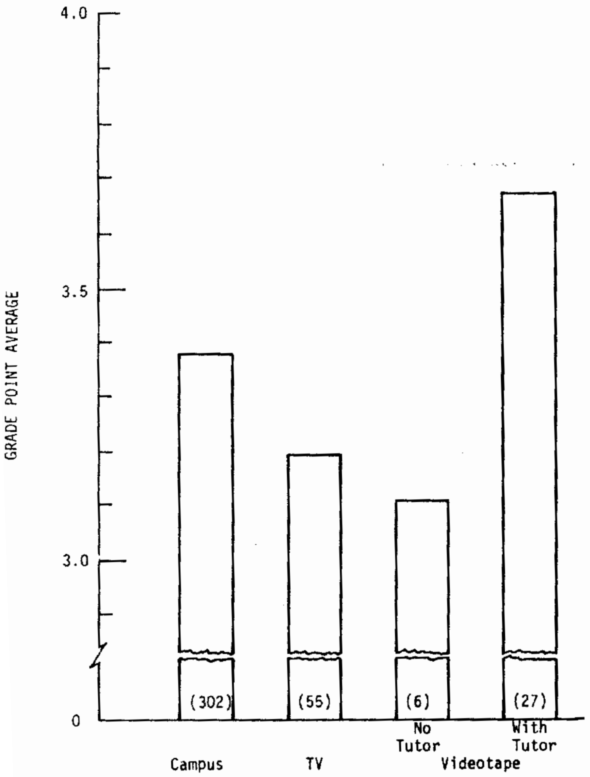

Fig. 2. Results of tutored videotape instruction experiment (October 1973 to March 1974).

The tutor's main functions are: (i) to initiate and encourage stopping the videotape playback for the immediate resolution of problems; (ii) to answer, if possible, questions that cannot be resolved by the class; and (iii) to obtain answers and supplementary material from the on-campus instructor if necessary. Tutors are also encouraged to visit the on-campus faculty once or twice a quarter to become familiar with the course syllabus and to discuss any recurring problems that their students have. The tutor is not responsible for grading homework or assigning course grades.

5) Students and tutors are urged to stop the videotape whenever they have problems or questions or whenever some particularly important concept has been presented. Certain obvious cues are frequently used by the tutor to initiate these discussions. For example, each time a substantive question arises in the on-campus class, the tape is stopped and the TVI class attempts to generate the answer before the taped lecture proceeds.

In addition to extensive group interaction during the lectures, students are encouraged to discuss problems with each other and with the tutor outside the viewing period. Since the tutors and students are known to each other through their common employment, there is ample opportunity for them to do so.

6) Careful records are maintained of TVI student performance on both homework and examinations. Their performance is regularly compared with that of regular students in the campus classroom and local off-campus students receiving the same courses by way of ITFS.

The homework and test performance of the TVI students is analyzed by the Stanford TVI staff and the results are discussed with the tutors by telephone. Corrective measures are suggested when necessary. In addition, course evaluation questionnaires are given to the TVI students in order to assess their attitudes and reactions to the program.

Initial experimental results. After the first two quarters of operation, the TVI experimental program was evaluated by comparing the course performance of the TVI students to that of both the on-campus students and the HP students taking the same courses by live television. One result of this evaluation is shown in Fig. 1, which is drawn from data gathered during the autumn and winter quarters of the 1973–74 school year. This figure shows the grade point averages of the TVI students for all courses taken under the program plotted against their admission qualifications, the latter being a composite of corrected undergraduate grade point averages (GPA's) and the quantitative component of the graduate record examination score. (The correction to the undergraduate GPA was based on prior history of performance of students from the same school in doing graduate work at Stanford.) Also shown in Fig. 1 are similar data for on-campus graduate students taking the same courses as the TVI students. The regression line shows the best linear least-mean-square fit to the on-campus student data, from which the average expected performance may be obtained for a student with given qualifications.

It is apparent from Fig. 1 that as a group the TVI students out-performed their on-campus counterparts; that is, the average GPA of the TVI students (represented by the point labeled SR in Fig. 1) is higher than that of the on-campus students (labeled SU in Fig. 1), even though the average of the admission qualification scores for the TVI students is substantially lower than that of the on-campus students. To make a more refined observation, it is convenient to divide the TVI students into two groups: those with admission qualification scores $\gtrsim 2$, who could have been admitted to the university as regular graduate students, and those with admission qualification scores substantially < 2 who would not have been so admitted. In terms of these subgroups, the data show that:

1) The subgroup that would have been granted admission did extremely well; in fact, their performance was essentially independent of their actual admission qualification scores.

2) The two students with the lowest qualification scores did quite acceptable work (B or better) even though they could not have been admitted to the Stanford Graduate School based solely on their admissions data. However, on the basis of their continued record of acceptable TVI performance, these students were subsequently admitted to the university and have now completed the master's degree program with creditable performance.

In Fig. 2, the grades of the TVI students are compared with those of the on-campus students and those of the students receiving the same courses by ITFS. The 302 on-campus students achieved a GPA of 3.38 out of a possible 4.00, which is typical of graduate electrical engineering students at the master's level. The students participating in the same courses by ITFS with audio talkback capability to the classroom had a GPA of 3.19, still quite acceptable but nonetheless below the on-campus students by almost a third of a grade point. This result is made even more remarkable when we recall that several of the TVI students had marginal academic qualifications that would have made their admission to the Stanford graduate program very unlikely. It is also interesting to note that the performance of students at Santa Rosa in the videotape courses without local tutors was substantially below that of all the other groups, although the data in this case are very limited.

The total number of courses taken by students studying from videotape without a tutor is so small that the result has no statistical significance. However, a similar result has been obtained recently by Anderson (*6*) in a much larger experiment. In particular he finds that both student satisfaction and course performance tend to decrease as the delivery method is changed from on-campus lecture to live TV to nontutored videotape.

It is sometimes argued that the industrial experience of the TVI students accounts for their outstanding performance in these courses; but the TVI students are drawn from the same population as the students studying by ITFS whom they out-performed, so industrial experience or motivation cannot account for these results. Furthermore, other experiments show that on-campus TVI students also out-perform on-campus students who attend the regular lectures.

It is also natural to question the degree to which the results may be due to a Hawthorne effect. However, the Santa Rosa TVI students have continued their superior performance for 3 years.

Continuation of the TVI Industrial Program

Because of the initially encouraging results with the Santa Rosa industrial TVI students, the university gave permission to continue the program and to incorporate TVI courses into an accredited graduate degree program. New students at the Santa Rosa plant of Hewlett Packard entered the program in both 1974 and 1975; and the program was further extended to include Hewlett-Packard plants in San Diego and Boise and the Sandia facility in Albuquerque.

At the end of the 1975 to 1976 school year, after 3 years of operation, a total of 1803 quarter-units (approximately 600 courses) of graded course work, plus a considerable number of ungraded seminars, have been completed by 82 TVI students, with 65 different tutors having been involved in the program. The overall GPA of the TVI students for this work is 3.37. If we exclude from this group students whose academic qualifications were below those normally required for Stanford admission, the GPA rises to 3.59 compared to an on-campus average of 3.43 for the same courses. In other words, the TVI students who are qualified for regular admission (48 students) have continued to out-perform the on-campus students; and the poorly qualified TVI students have continued to do very acceptable work.

On the basis of these results it seems reasonable to conclude that, for science and engineering courses, the TVI format is at least as good as the other methods of delivery with which it has been compared. We believe the method can be used successfully for other types of courses, though we have no data to support this hypothesis. We have, however, used the technique in two on-campus experiments to determine whether full-time graduate students could also benefit from TVI.

On-Campus TVI Experiments

The first of these experiments was performed over two successive quarters in a graduate electrical engineering course that was large enough that several TVI groups, varying in size and with different tutors, could be formed for comparison with the large live lecture class. The course was taught by a faculty member who had already established a reputation as a particularly effective instructor for both regular classes and off-campus TVI groups. Three TVI groups were formed, two of these being led by the same tutor. The tutors were chosen from a set of students who had performed equally well in the course during the previous year. Both tutors were very much interested in the subject and were also interested in teaching as a career. However, their possible teaching styles were known from previous experience to be somewhat different. Where one tutor tended to answer questions directly when the tape was stopped, the other tended to encourage his group to find the answer. The first tutor was given a group of six students (labeled group 3 in the following figures). The second was given two

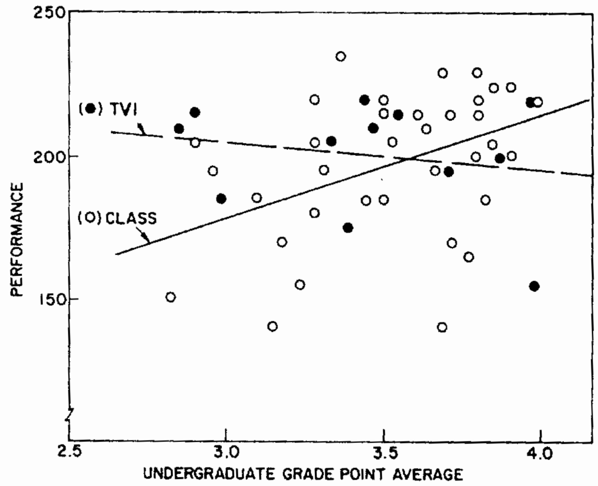

Fig. 3. Classroom and tutored videotape instruction student performance. Foreign students and honors cooperative students were eliminated from both the TVI groups and the in-class group for this comparison because they formed very different proportions of the groups.

groups, one with 12 members (identified as group 1) and one with six (group 2).

The separate TVI groups were too small for statistically significant differences to be manifested in their educational effectiveness. However, as illustrated by Fig. 3, the combined data show that the TVI method was at least as good as live instruction. Furthermore, for students with lower admissions qualifications, the TVI method of teaching appeared to be more effective than the regular classes. In fact the regression line for TVI students in Fig. 3 suggests that the course performance is essentially independent of the standard measures of academic ability. Note that this finding agrees with the results given in Fig. 1 for the subgroup of TVI students whose admission qualification scores were sufficient for them to be admitted to the university as regular graduate students.

Student opinions of the TVI format were also collected at the end of each quarter and showed a generally enthusiastic response to the method. Some characteristic features of their responses are shown in Table 1. With respect to the effect of group size, a comparison of groups 1 and 2 (same tutor) shows that the smaller group was generally more enthusiastic about the TVI experience than the larger group. This same general result has been repeated in our industrial TVI groups, and a consideration of all of our present data on group size leads us to the tentative conclusion that the method works best when the group size is between 3 and 10.

Table 1 also contains some specific information about the influence of tutoring styles that is consistent with our general observations. The students studying with the tutor who tended to answer questions directly (group 3) were less pleased than students in a group of equal size with a tutor who tended to draw them into the discussion when the tape was stopped.

The second set of experiments, performed during the winter quarter of 1976, was conducted with the second half of an introductory graduate engineering-economics systems course in which the regular course professor was away from campus. In the absence of a suitable lecturing replacement, videotapes of his course from the previous year were shown to the regular class. A professor from the general subject area viewed the tapes with the class and answered questions primarily at the end of the lecture. For technical and scheduling reasons, the tapes shown to the large class could not be stopped during the lecture for thorough discussion.

Table 1. Student reactions to tutored videotape instruction on campus. Question A was, "How would you rate your overall educational experience with TVI as compared to a large live lecture class?" Question B was, "How do you feel about taking another course in this manner?" To obtain averages and standard deviations a preference scale running from +1 (definitely superior or highly favored) to −1 (definitely inferior or definitely do not prefer) was employed.

Rating	Groups 1 (N = 12)	2 (N = 6)	3 (N = 6)
	Question A		
Definitely superior	4	3	
Superior	6	3	1
About equal	2		4
Inferior			
Definitely inferior			
$\bar{X}$	0.58	0.75	0.1
Σ	0.36	0.27	0.22
	Question B		
Highly favor	7	6	3
Favor	3		
Neutral	2		2
Prefer not			
Definitely not			
$\bar{X}$	0.71	1.0	0.6
Σ	0.4	0.0	0.55

Two small TVI groups were formed by random sampling from groups of students who had demonstrated high and low performance in the prior quarter, with each group having a separate tutor. A control group was also formed, consisting of 22 students who watched the videotape in the large class.

With respect to course grades, no statistically significant difference was found in the performance of the TVI and control groups, partly because of the small size of the sample groups, although again the data were consistent with the conclusion that the TVI students did at least as well as the regular class, and that the students of lower ability benefited more by the TVI educational method. In fact the comparison was frustrated by the fact that all low-ability students in the control group dropped the course.

However, a pronounced difference was observed in student attitudes toward the use of a videotape with and without the combined tutor and tape-stopping features. These results are shown in Table 2, where the responses to several questions are recorded for the three groups of students (low ability, high ability, and control). Each question was answered on a preference scale which ran from +1 (strongly agree) to −1 (strongly disagree). Note that the high-ability TVI group was on the average highly enthusiastic on all counts, though its course performance was almost identical to what it had been during the previous quarter in the live lecture class. In fact, the high-ability TVI group stopped the tape on an average of every 5 minutes.

Observations

The TVI technique was invented in an effort to provide the benefits of both lectures and small group discussions to off-campus engineering students. Experience gained from 3 years of operation of the program suggests that the TVI technique is at least as effective as either classroom instruction or live TV with audio talkback capability, for both on-campus and off-campus students. However, our data do not yet permit a rigorous statistical test of this conclusion to be made. We are also unable to generalize to subject areas other than engineering and science, though we believe the general principles of the TVI format will apply to a wide range of subjects and audiences.

To assist in considering how the method might be applied to situations other than those described above, we have enumerated the factors which we believe to be critical to the effectiveness of the TVI format:

1) The attitude, personality, and instructional style of the tutor are very important. The tutor should be interested in helping the students in his group. He should attend all or nearly all the videotape sessions. His competence is important, but it is better that he not be so overqualified that he becomes bored or impatient with a lack of understanding in the students. Compensation of the tutors is important for a continuing program.

2) Group size is also very important. If there are fewer than three students opportunity for effective interaction is lacking and the method tends to be expensive. Group size greater than 8 to 10 tends to inhibit discussion and reduce the frequency with which the tape is stopped. A group size of 3 to 8 seems optimum, although this can vary with student personalities and acquaintance with each other.

3) Depending on the maturity of the student, commitment to a degree program or similar educational objective seems to be important for sustaining interest and motivation. Certainly for most students completion of graded problems and examinations results in a more productive educational experience.

4) Active classroom participation in the live class is desirable. For the subjects and audiences served to date, unrehearsed, unedited videotapes of classroom lectures may be used and, in fact, may have more "presence" and be more interesting to watch than tightly scripted, professionally produced lectures.

5) It is important that the instructor be well organized, knowledgeable in his subject, and free of annoying mannerisms. The charisma of a good instructor is emphasized on the videotape.

6) For students employed in industry, attitudes of management play a very important role in the success of a continuing program. Job pressures that create long hours and interfere with family life markedly increase the difficulty of pursuing an educational program.

7) Continued management and evaluation of a TVI program needs to be the concern and principal responsibility of a designated person who should provide liaison between the academic institution and the TVI students. Many details require timely attention that would otherwise not be given by either the instructor or the company.

None of these factors pose unmanageable requirements. With attention to group size, good tutoring, quality of recorded educational material, adequate handling of supplementary materials, and grading of problems and examinations, the TVI methodology can provide an excellent educational experience and opportunities for needed education in otherwise difficult or impossible situations.

Given that it can accomplish important educational objectives, it seems worthwhile to summarize the principal advantages TVI has over both in-class instruction and live television:

1) It is (or can be) educationally more effective than either classroom or televised instruction, especially for marginally qualified students. This is primarily because it permits students to ask more questions and, through organized discussion, to find more answers for themselves than they could in either of the other formats.

2) TVI is cheaper than either classroom or televised instruction from the point of view of marginal costs. It does not require new teachers, new educational plant, or expensive broadcast facilities. Our operating experience shows that TVI can be provided at a marginal cost of $2.20 per student per lecture for groups of 10 students. The marginal cost of instruction by "real time" television on the Stanford ITFS system is $2.43 per student per lecture.

3) It makes good use of teaching resources by using faculty for course preparation and paraprofessional tutors for discussion of the lectures. For this latter function it draws on the substantial (if latent) interest in tutoring that exists in a large segment of the population.

4) It allows instruction to take place at the convenience of the students. It is not bound by either the academic calendar or a broadcast schedule.

These advantages are substantial, and while over-generalizing is dangerous, we nonetheless feel confident that TVI can be successfully extended to large-scale applications, at least for courses in science and engineering. We believe the method can also be successfully extended to other subject areas.

Table 2. Campus student attitudes toward tutored videotape instruction. The abbreviations are: SA, strongly agree; A, agree; N, neutral; D, disagree; SD, strongly disagree. The attitudes examined were: 1, feel more favorable toward this method of instruction at end of course than when course began; 2, prefer this method of instruction to lectures in large classes (50 or more students); 3, learned more from this course than from other courses due to the instructional method; 4, asked more questions in this class than in other classes; 5, learned more from questions and comments of other students than in other courses; 6, felt more free to ask questions and express myself than in other courses; 7, would recommend this course to a friend exactly as I took it. A numerical performance scale was established for quantification of the data: SA = 1, A = 0.5, N = 0, D = −0.5, SD = −1.0; $\bar{X}$ and Σ are means and standard deviation, respectively.

Group	SA	A	N	D	SD	$\bar{X}$	Σ
			Question 1				
Low	2	3	2	0	0	0.5	0.41
High	1	4	1	0	0	0.5	0.32
Control	0	7	6	6	3	−0.1	0.54
			Question 2				
Low	4	2	1	0	0	0.71	0.39
High	5	1	0	0	0	0.92	0.20
Control	1	6	5	5	3	−0.075	0.59
			Question 3				
Low	2	2	2	1	0	0.36	0.56
High	4	1	0	1	0	0.67	0.61
Control	1	3	6	10	2	−0.2	0.5
			Question 4				
Low	0	5	1	1	0	0.29	0.39
High	3	3	0	0	0	0.75	0.27
Control	0	0	10	7	4	−0.36	0.39
			Question 5				
Low	2	4	0	1	0	0.5	0.5
High	2	3	1	0	0	0.58	0.38
Control	0	0	5	9	8	−0.57	0.39
			Question 6				
Low	4	1	1	1	0	0.57	0.61
High	4	1	1	0	0	0.75	0.42
Control	0	0	8	7	7	−0.48	0.42
			Question 7				
Low	3	3	0	0	1	0.5	0.71
High	1	2	2	1	0	0.13	0.74
Control	1	4	7	6	4	−0.18	0.57

References and Notes

1. P. W. Jackson, *The Teacher and The Machine, Horace Mann Lecture, 1967* (Univ. of Pittsburgh Press, Pittsburgh, 1968).
2. J. F. Gibbons, "Federal initiatives for bringing communications technology to the service of education," position paper for the Newman Task Force on Higher Education and the President's Science Advisory Committee. A partial summary of the paper is published in *Aspen Notebook: Cable and Continuing Education*, R. Adler and W. S. Baer, Eds. (Praeger, New York, 1973), pp. 127–132.
3. G. C. Chu and W. Schramm, "Learning from television: What the research says" (Educational Resources Information Center Report No. Ed-014-900, Stanford University, Stanford, 1967).
4. W. Schramm, "What we know about learning from television," (Educational Resources Information Center Report No. ED-002-561, Stanford University, Stanford, 1971).
5. J. M. Pettit and D. J. Grace, *IEEE Spectrum*, May 1970.
6. R. M. Anderson, Jr., personal communication.
7. We thank J. G. Linvill for encouragement and support, J. Lindsay and R. Latta for assistance with the statistics, and several of our colleagues for helpful reviews of the manuscript. The National Institute of Education provided support for the statistical analysis presented and also commissioned a paper from which this article was abstracted.

Impact of the Electronics Revolution on Industrial Process Control

Acceptance of advanced digital communication and control systems in the industrial plant will accelerate.

Lawrence B. Evans

The first computer control system went on-line in an industrial plant in 1959. Since then, there have been remarkable advances in our ability to acquire, process, and transmit information electronically. Developments in the technology of digital computer hardware, software, basic sensors, and all forms of communication offer the potential for industrial process control systems that are highly automated and provide improved operating performance.

The Role of Process Control in Industrial Plants

The focus in this article is on the "process industries" as opposed to the manufacturing industries. Products of the process industries include chemicals, petroleum, metals, electric power, pulp and paper, food, cement, and textiles. Their plants manipulate the composition of materials by chemical reaction, purification, and blending of components to convert raw materials and energy into more valuable products. A modern chemical plant is shown in Fig. 1. The earliest applications of computer control were in the process industries, where instruments were available to monitor the continuous flow of a product and to send the data to the computer, which could then direct changes in the process by adjusting valves and switches.

Automation in the manufacturing industries—automobiles, appliances, electronics—is beyond the scope of this article. These industries manipulate the geometries of their raw materials so that discrete parts are assembled to form products. Computers are being used on the factory floor to run machine tools, track the contents of a warehouse, test products, and so forth, but the methods of measurement and control are basically different from those used in the process industries, and the problems of automation are greater (*1*).

Industrial processes are designed to operate in either a continuous or a batch mode. In the first, materials flow continuously through the plant from one processing unit to the next. At each stage, different operations are performed, such as heating, cooling, mixing, chemical reaction, distillation, drying, and pressurization. For most operations, there are optimum conditions of temperature, pressure, and residence time at each stage.

In the batch mode, the material being processed stays in one place (such as in a reaction vessel), and the process steps are carried out over time during the batch cycle. There is an optimum schedule of such factors as temperature and pressure. For large-scale production, engineers have traditionally tried to develop continuous processes, because they are easier to instrument and control, require less labor, and do not waste time in emptying, cleaning, and refilling vessels between batch cycles (*2*).

Flow rate is by far the most common variable manipulated, whether by adjusting a valve, turning a pump on or off, or by other means. The measured variables in addition to flow rate are normally temperature, pressure, chemical composition, and liquid level. A typical plant, such as one for manufacture of ethylene or ammonia, will have several hundred control valves and more than a thousand measured variables. Changes are made in the operation of the process on a time scale ranging from a few seconds to a few hours.

The elements of a control system are shown in Fig. 2. The important functions are measurement, control, actuation, and communication. Measurement refers to the sensing of variables such as flow rate, temperature, pressure, level, and chemical composition, and the transmission of the measurement to the controller. Control is the decision-making operation; it compares the measured state of the process with the desired conditions and decides how the variables should be manipulated. Actuation is the means by which the operating variables are manipulated; typical actuators are valves, rheostats, switches, and relays. Communication includes the display of information to the plant operators as well as the transmission of important variables to the plant management.

The organization of a plant control system in a hierarchical structure is shown in Fig. 3. The lowest level is occupied by the control computer that regulates a single process unit to hold it to the desired operating conditions and move the unit to a safe condition in emergencies. The next step is a computer responsible for coordinating several units, for scheduling operations, and for optimizing the plant's performance. At the top level is the corporate control com-

---

The author is professor of chemical engineering at Massachusetts Institute of Technology, Cambridge 02139.