organelle replication in tumor cells will prove to be a consequence of abnormal surface structure.

Summary

Experimental work on the ciliate *Stentor* has provided direct experimental evidence for the hypothesis that the cell surface controls the time of cell division and also plays a part in determining the replication of the macronucleus and basal bodies during division. Experimental studies on amphibian and marine invertebrate eggs have led to similar conclusions and therefore provide a bridge between the work on *Stentor* and the work suggesting control of cell division by the cell surface in the mitotic divisions of mammalian cells. The observations on egg cells and *Stentor* have further suggested that it may prove necessary to invoke mechanisms involving propagated structural change rather than diffusion to explain at least some of these phenomena.

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Educational Challenges for the University

Significant educational progress and innovation require superior talent and a changed university role.

F. Reif

The present educational role of the university seems incongruous with its expected role of intellectual leadership. Indeed, one might naively expect that the university would regard its educational function as crucially important since it is the only institution entrusted with high-level educational tasks (while carrying on research functions somewhat similar to some of those pursued by other institutions, such as the National Institutes of Health or Bell Telephone Laboratories). One might suppose that the educational function of the university would have assumed even greater importance in recent years because of the enormous growth of knowledge and the large increase in the number of people demanding to be educated. Finally, one might expect that the university would be a spearhead in educational innovation since it has played such a successful innovative role in most other areas (such as the sciences or technology). Interest in educational innovation might be presumed to be particularly high since progress in this area would have a direct bearing on the university's own mode of functioning. Furthermore, there has been thoughtful discussion about the great potential of a prospective "educational revolution." For example, the Carnegie Commission on Higher Education recently published a report suggesting a blueprint for the implementation of such a revolution (*1*).

These expectations are in marked contrast to current realities. In actuality, the university is largely preoccupied with the maintenance of standard educational programs and seems content to formulate educational policy in terms of mundane criteria such as degree requirements, the faculty-student ratio, or the number of class-contact hours. Except for some graduate education closely connected with the research of the faculty, the university's norm in the area of education is reasonable adequacy, rather than excellence or innovative leadership. The university does not systemati-

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cally encourage faculty members to turn their talents to educational endeavors; in fact, such endeavors are usually regarded as being of dubious legitimacy compared to more prestigious activities. (Outstanding educational work by faculty members is thus more often a volunteer activity based on idiosyncratic personal preference than an activity deliberately fostered by the university.)

Moreover, the educational mode of functioning of the university today is basically not very different from what it was 50 years ago, all the talk of an impending educational revolution notwithstanding. Educational innovations are few in number and often marginal in their impact. Nor is this situation surprising, since the university, unlike any progressive industry, is not in the habit of improving its own performance by systematic investment in innovative research and development. Indeed, the resources allocated by the university to educational innovation are usually miniscule or nonexistent.

The persistence of a situation where the educational role of the university is not given high priority has several consequences. (i) Significant questions are not being raised. (Indeed, although medicine is rarely confused with mere clinical practice, there is a tendency to view education narrowly as mere classroom teaching and thus to ignore important issues.) (ii) Promising directions are often pursued poorly or not at all. (iii) Education tends not to attract the kind of first-rate talent that might achieve significant progress.

The present educational role of the university is neither desirable nor necessarily immutable. Is it too far-fetched to suggest that the university should take education at least as seriously as the Bell Telephone Company takes communication? The university would then be expected to further progress in education by engaging deliberately in suitable research, development, and deployment. In short, it would have to view its mission, in education as well as in its other functions, as one of carrying out excellent work, developing new ideas and methods, and fostering the diffusion of innovations throughout the rest of the society.

If one accepts the desirability of a more significant educational role of the university, several questions arise. What are some of the educational challenges which might fruitfully be addressed? What essential requirements would have to be met to insure meaningful progress? What concrete steps for implementation might be considered? The following paragraphs are intended to suggest some possible answers to such questions.

Intellectual Challenges

A university seriously interested in its educational function cannot be content with the mere perpetuation of educational patterns hallowed by traditions or by entrenched beliefs. It must be willing to face the challenge, worthy of the role of the university, of devoting to education the kind of searching thought commonly bestowed on scientific or engineering fields, and of promoting the translation of new ideas into practice.

There are problems worthy of thought because of their purely intellectual interest, quite apart from their ultimate practical implications. A few examples may suffice.

Reliable knowledge about effective processes of instruction is scanty. Suppose one wanted to achieve the reproducibility necessary for improved understanding and to make even the most rudimentary progress toward any kind of "theory of instruction." Then the minimum requirement would be to proceed systematically by specifying operationally the goals to be attained, by formulating instructional models, by specifying explicitly all the steps of the instructional interaction, by experimentally testing to assess the effectiveness of the instruction and the validity of the models, and by making successive revisions for cumulative improvement.

Although any scientist would routinely be so systematic when approaching work in his own field, the same scientist in academe is rarely prone to raise systematic questions about his instructional activities. Intellectual curiosity at the university should not be so compartmentalized. The challenge of contributing creatively to a useful theory of instruction may be excessively demanding; but more systematic approaches to instruction can realistically be pursued and would lead to enhanced awareness of significant questions and hence improvement in the quality of teaching.

An appreciable amount of instruction, especially at the university, is supposedly for the purpose of training people in the use of concepts and in problem-solving skills. But such teaching tasks are ordinarily performed haphazardly and poorly. Concepts and principles are often taught as results to be memorized, problem-solving skills are merely demonstrated by example, and discovery processes are usually not explicated. Indeed, more attention seems to be paid to teaching explicit strategies in games such as chess than is usually paid to problem-solving strategies in science courses. Similarly, people interested in artificial intelligence appear to spend more effort teaching computers to deal with cognitive processing skills than is customarily devoted to teaching such skills to human students.

Yet there are some fascinating questions to be explored. Can one formulate explicit models describing how well-performing thinkers organize their cognitive maps to handle concepts effectively and what heuristic strategies they use to solve problems (*2*)? As a subsequent question, can one formulate models specifying instructional processes for teaching someone improved cognitive maps and heuristic strategies that will be successful in enhancing his thinking skills? Such questions are certainly intellectually substantive, if not overly ambitious. The very attempt to focus attention on questions of this kind would significantly change present attitudes toward many educational tasks.

The preceding comments can be viewed in a broader context. It is likely that today's students will live in a world which will be increasingly complex and rapidly changing, where many of the most significant problems (both pure and applied) will transcend the boundaries of traditional disciplines, and where alternative value choices will often need to be analyzed with great care. Yet universities rarely address the problem of providing education well designed to prepare students to function effectively in such a world. Any serious attempt to deal with this problem would require careful thought devoted to the following difficult questions: Can one synthesize, and impart to students, judiciously selected knowledge and principles of wide applicability transcending disciplinary boundaries? Can one then teach effectively the

necessary skills of independent learning and problem-solving which will enable students to extend such a knowledge base flexibly along any direction of future need?

If universities were prepared to subject the functioning of the educational system to the kind of critical analysis commonly bestowed by applied scientists on other complex systems, they could also address themselves fruitfully to some challenging questions with direct practical implications. The nature of these questions will become apparent from the following remarks.

Shortcomings in Current Models of Educational Delivery

Our present educational delivery system is largely based on a "personal contact" model. According to this model, students are to be taught by being brought into contact with a teacher who plays the central instructional role (even when he uses textbooks or other auxiliary curricular materials). This educational model originated centuries ago when the number of students was relatively small and when information transmission was largely restricted to direct oral communication. The model is still quite appropriate in certain contexts, such as advanced graduate education, where the small number of students permits a master-apprentice relationship. But in most other situations, particularly those involving many students, our familiarity with the model should not blind us to its severe limitations. Among these are the following.

1) Teaching talent and time are necessarily scarce resources. The best available teachers can obviously not be placed into more than a few classrooms, nor can any teacher ordinarily be expected to spend several years preparing for one instructional assignment. As a result, the vast majority of students receive instruction from teachers who are neither very talented nor optimally prepared.

2) There is a wasteful redundancy of effort because any one teacher often does the same thing repeatedly and because many different teachers often engage in the same tasks. As a result, scarce human talent is not exploited for the optimum effectiveness and benefit of the students.

3) It is difficult to introduce and deploy educational innovations because it is necessary not only to reach the students, but also to train a large body of teachers who may have only a limited ability or willingness to use new approaches.

4) Since the model requires that students be brought into personal contact with a limited number of available teachers, it becomes necessary to resort to "batch-processing" of students, that is, to use the familiar process of assigning students to classes. Students are thus forced to do their learning at a particular place and at a particular time according to some prescribed schedule. (This inflexibility may even make learning impossible for some students, such as those who need to work or to take care of children.) Since students are handled in groups, little allowance can be made for individual differences between students. Thus, students are forced to learn at the same rate irrespective of their ability or background, and teaching methods cannot be adapted to the personal needs of individual students. Finally, the student who is handled as part of a large class is placed in the predominantly passive role of listening or reading, despite the fact that he must be trained for tasks which will require him to play an active role.

An excessive reliance on the personal-contact model thus leads to some inherent difficulties of ineffectiveness, inefficiency, and inflexibility. These limitations can be transcended by thinking of the educational process more broadly in terms of a "general interaction" model, according to which the student is taught by interaction with any suitable outside system. This system need not necessarily be a human teacher, but might equally well be a book, a film, a computer, or another student. Keeping in mind the much larger range of alternatives made possible by such a general model, one may then raise the following question: How can one deploy an educational system with limited resources and new techniques most effectively to provide the highest-quality education to individual students? This is a substantive question worthy of exploration by the university and likely to suggest changed modes of educational delivery with far-reaching implications.

Let us discuss briefly some of the directions which might usefully be pursued.

Alternative Modes of Educational Delivery

If one abandons predominant reliance on a personal-contact model, one may contemplate the following alternative mode of educational delivery: A concentrated investment of effort is undertaken, involving the best available talent, time-consuming work, extensive prototype development, and adequate testing. The aim of this effort is to produce materials which are packaged in such a form that they can be distributed widely and that they can provide every student with individualized instruction permitting him to learn effectively with minimum (or no) reliance on intermediaries such as teachers. The essential feature of this mode of educational delivery is thus effective packaging of the best instruction addressed directly to every individual student.

This mode of delivery should not seem too strange or inhuman since it has to some extent been used fruitfully for a long time. For example, the high school student who goes to the public library to read books by Bertrand Russell or Einstein has, through packaging in book form, access to a kind of thinking which no secondary school teacher could be expected to provide. Similarly, the music student of today has, through packaging in phonograph records, direct access to the best interpretation of the Beethoven quartets, irrespective of the quality of his local music teachers.

Modern technology has, however, vastly enhanced the potential impact of direct educational delivery through effective packaging, particularly if sufficient talent and effort are invested in the initial production. (i) Technology permits increasingly cheap large-scale distribution. (ii) Packaging can be achieved in more diverse and useful forms, for example, in printed form (by books), in the form of sound (by records or audio tape), and in visual form (by film, television, or video tape). (iii) Modern techniques (such as programmed or computer-aided instruction) permit one to package not only one-way communication, but interactive communication simulating a dialogue (*3*).

Direct educational delivery based on effective packaging can overcome many of the limitations of the personal-contact model and has the following po-

tential advantages: (i) High-quality instruction by the best talent can, in principle, be provided reproducibly for every student. (ii) Students can be taught in a more flexible, individualized, and effective way than in the traditional classroom style (since packaged instruction allows students to learn at their own rate wherever they like, provides various paths adapted to the differing needs of individual students, and can be interactive so as to keep students constantly in an active role). (iii) Human talent can be used more effectively by freeing teachers to perform the functions for which they are most uniquely qualified (for example, preparing instructional materials or providing personal contact where it is most valuable). (iv) Some economies might be realized by avoiding wasteful duplication of effort and exploiting the advantages of large-scale production. (v) The diffusion of educational innovations can be appreciably facilitated.

The preceding arguments must be tempered by some caution. Packaging of instruction can only be successful if proper attention is paid to the quality of the content and to adequate insight into instructional methods. If garbage is packaged, marvelous technology will merely be used to distribute educational garbage on a large scale. Thus, the sole deployment of new techniques is not enough; they must be properly utilized through the investment of superior talent. Furthermore, packaging must be used judiciously. Although packaging of high-quality instruction for direct delivery to the individual student could be used much more extensively with major benefits, this does not imply that all education should be indiscriminately packaged.

Another change in educational delivery, besides packaging, involves the use of the optimum combination of methods to achieve specified educational goals most effectively and economically. This approach has been used far too little despite its obvious merits. The common practice is to set about every educational task by resorting to some standard traditional method (such as the lecture or discussion section) without analyzing the distinct instructional functions which should be performed and the best possible means to implement each one of them. Since newer techniques make available a much larger range of possible instructional alternatives, a "systems approach" seeking the optimum combination of methods can be pursued much more efficiently than in the past. (For example, textbooks might best be used for the presentation of ideas, films for the observation of phenomena in time, programmed or computer-aided instruction for teaching problem-solving skills which require active student involvement, lectures for instilling enthusiasm and providing role models, personal tutoring for assistance with special questions, and so on).

Implications of New Approaches

All of the educational ideas which we have discussed could fruitfully be pursued by individual teachers. For example, any particular instructor could approach his (or her) teaching tasks more systematically with greater attention to the teaching of conceptual skills. He could replace a predominant reliance on lectures by a more effective combination of teaching methods. He could use packaged instructional materials to greater advantage, especially if he modified the format of his courses so as to make them more adaptive to individual students [for example, by using the format of "Keller plan" courses which have recently come to be used in several schools (*4*)]. He could even be sufficiently ambitious to undertake the preparation of new instructional materials in one of the more interactive packaged forms (such as programmed or computer-aided instruction).

But such educational ideas would have a much more far-reaching impact if universities fostered them systematically by encouraging and facilitating significant educational activities by a sufficiently large number of talented individuals. Universities would then be less concerned with routine teaching, but more involved with the production of excellent instructional materials which could be used internally, as well as exported for use by students off campus or in other educational institutions. They would also be more interested in the advancement of education at all levels and would train talented people to acquire the skills necessary for educational innovation. The roles of teachers would be changed (and the criteria for assessing their performance would have to be correspondingly modified). Instead of engaging in conventional classroom instruction, more teachers would be concerned with preparing packaged instructional materials. Others would rely more heavily on such materials while reserving their own skills for activities where they are most uniquely valuable (for advising students, diagnosing their difficulties, engaging them in open-ended discussion, and so forth). Most important, students would receive better instruction with far greater flexibility of timing and scheduling, and without the necessity of continuous residence at a campus. Finally, it would be easier to provide special help for students from disadvantaged backgrounds and to make available effective programs for adult education.

Need for First-Rate Talent

The potential of the educational ideas discussed in the preceding sections can only be realized if they are implemented with adequate care and competence. But the pursuit of such ideas is no trivial matter. It is a demanding task to gain increased knowledge designed to make instruction more reliable and effective, particularly in the realm of higher cognitive abilities. It is also an ambitious undertaking to achieve changed modes of educational delivery which do not merely serve mediocre wine in fancy new bottles, but which have substantive effectiveness and the requisite high-quality input to make delivery worthwhile. Challenging tasks of this kind require first-rate talent. In discussions of a prospective educational revolution most of the attention is usually focused on new hardware and software. One must not forget the crucial importance of the talent needed to develop and intelligently utilize new approaches as well as new technology.

Indeed, the prerequisite for significant progress in education is a sufficient investment of superior talent. Hence, it is necessary to devise adequate mechanisms for attracting such talent and facilitating its effectiveness. (Such mechanisms are particularly needed since top talent has traditionally not been prone to address itself to educational problems.)

The university appears to be the proper institution to further educational progress and to provide the necessary talent. It is supposedly entrusted with

a leading educational role and it has a tradition for innovative excellence in many fields. Moreover, it provides a unique reservoir of latent talent which could be channeled into educational efforts. Indeed, it would be difficult to make effective educational progress in settings where it would not be possible to draw on this pool of talent.

A university interested in playing an innovative educational role should make provisions for two kinds of talent actively involved in education: (i) A special "core group" whose central intellectual commitment is to the advancement of education. This relatively small group would be concerned with research directed toward improving educational models, methods, and technologies. It would also engage in prototype development designed to introduce significant educational innovation not only at the university, but also at all other levels. (ii) A larger general group concerned with educational deployment in various areas. This pool of talent (consisting of faculty members in various fields who are more peripherally and temporarily committed to educational tasks than the core group) would engage in the creative synthesis necessary to produce various new curricular programs by the combination of expertise in specific fields with the application of the most effective educational techniques.

The following are some concrete proposals as to how these kinds of talent might be provided by the university.

Suggestions for Implementation

A special core group of talent for the advancement of education could best be established as a cohesive interdisciplinary group having many of the prerogatives of a department or a research center. The group should be above the critical size necessary to achieve stability and mutual intellectual stimulation of its members. It is also important that it be provided with effective intellectual leadership. The interdisciplinary character of the group is desirable since education depends on, and is relevant to, many diverse fields.

The group should maintain good contacts with major existing university departments (as well as with any existing school of education) in order to utilize the talent in these and, conversely, to promote educational innovations in them. It is, however, important that the group be a distinct entity, independent both of the departments and of a school of education. Individual departments, being chiefly concerned with the advancement of their own disciplines, cannot be expected to divert scarce resources into substantial educational undertakings; furthermore, they are too separate to advance educational goals that transcend departmental boundaries. As for schools of education, most of them have traditionally been largely concerned with teacher training, particularly at the lower levels; furthermore they are, by themselves, not in the best position to attract the kind of talent needed.

The core group should have the power to recruit and appoint faculty members whose main commitment is to the advancement of education. Many of these appointments, although not necessarily all of them, should be made jointly (or otherwise affiliated) with existing departments or schools so as to maintain the desirable contacts mentioned previously. Adequate visiting and temporary appointments should be provided, as well as the nonpermanent positions needed to insure an adequate flux of younger people. It is imperative that high standards of quality be maintained in all appointments. The criterion of quality should not be more difficult to enforce than in many other fields since review committees would not try to judge teaching activities in a classroom, but rather visible and exportable output designed to have observable educational effects.

The core group should offer some courses and colloquiums on educational subjects. In addition, it would be desirable that it offer a graduate Ph.D. program designed to prepare students for careers devoted to educational innovation. Such a program would help to meet the need for people trained to contribute to an educational revolution, would accommodate the interests of some students presently enrolled in traditional departments, and would provide a healthy influx of young vitality into the activities of the group.

Let us now turn from the consideration of this special core group for the advancement of education to the establishment of conditions where a wider pool of faculty talent would be fruitfully involved in the development of innovative educational programs in a variety of fields. Specific suggestions for implementation are the following:

1) It is essential that the university provide legitimation and encouragement for worthy educational work by the faculty. This can be done by adequate attention to such work in the promotion of faculty, by giving visible recognition to the educational work of others (for example, by inviting visiting professors on the basis of their outstanding educational work), and by bestowing special awards and honors for educational achievements of wide impact (just as such awards are now given to individuals for substantive achievement in science or scholarship).

2) Worthy faculty can be given encouragement and time for undertaking educational projects by being appointed to special temporary positions which provide relief from ordinary responsibilities. Such positions could be specifically endowed (by the university or by private foundations) or could be provided by an existing special core group. (Similar positions now exist in some universities so that faculty members can devote themselves exclusively to scientific research for a year or two. There is no reason why such positions could not also be endowed for educational work.) Further encouragement to faculty members could be provided, at no extra cost, by allowing them to devote their sabbatical leaves to work in educational development.

3) Special grants could be made available to provide the resources needed for faculty members to carry out educational projects. A specified fraction of the university's yearly operating budget could be set aside for this purpose and could then be allocated after review of the merits of proposed projects (*5*).

4) Visible activities by the special core group could provide information and prototype models to encourage educational work by the larger faculty.

5) Educational efforts could be facilitated by setting up an educational service center which would provide access to educational information, to technological aids, and to advice on evaluation procedures.

Although no single one of the preceding suggestions is likely to be sufficient, a combination of several of them would be effective in encouraging a larger fraction of faculty talent at the university to engage in significant educational undertakings.

Existing Precedents

The proposals discussed in the preceding section are practical enough so that they could be implemented. They do not call for any grand redesign of our educational system, but merely for a judicious combination of administrative actions (some of which might be welcomed by a public clamoring for greater educational concern by the university). Indeed, recent developments at several universities provide specific precedents which might serve as partial models.

Some of these precedents have the characteristics of a special core group for the advancement of education. For example, at the University of California in Berkeley a Group in Science and Mathematics Education was created in 1968 to involve faculty members and graduate students from the regular science departments in innovative educational work. This group offers a graduate program leading to a Ph.D. degree in science education and maintains connections with the Lawrence Hall of Science (which acts partly as an educational research institute). The group has no powers of appointment, but must rely exclusively on the participation of faculty members from existing departments. The Massachusetts Institute of Technology has just created a Division for Study and Research in Education which will carry on educational research and offer courses. This education division is empowered to hire faculty members, both through joint appointments with existing departments and solely within the division. The University of Illinois at Urbana has a substantial commitment to educational innovation through the Plato project, a major development effort in computer-based education (*6*). This project has involved several faculty members and has begun to significantly affect educational delivery at the University of Illinois as well as at some other institutions.

A precedent designed to involve the wider pool of faculty talent in educational undertakings is provided by the University of Minnesota. This university plans to allocate ultimately 3 percent of its annual operating budget for the purpose of fostering educational improvements. (It has now reached the stage where it is setting aside about 0.7 percent for this purpose.) These funds are administered by a Center for Educational Development which is acting like an internal foundation. Thus, it receives proposals from, and awards grants to, departments and individual faculty members so that they can carry out various educational projects.

A last precedent of considerable interest is the recently established Open University of Great Britain (*7*). This institution is committed to a systems approach to the delivery of education and is engaged extensively in the production of educational packages addressed to a far-flung student audience who are away from any campus. In addition, the Open University has a core group of faculty (the Institute of Educational Technology) which cooperates closely with the wider faculty in the production and evaluation of educational programs.

These precedents suggest that proposals of the kind made in this article are realistic. Their implementation would, however, require intellectual leadership by some faculty members and administrative leadership by some top university officials. (Outside encouragement by some foundations that are interested in education might also be helpful.)

Summary

Traditional educational patterns are being perpetuated by universities with remarkably little questioning, despite their inherent problems and their limitations in meeting social needs. Yet it is apparent that education is a field ripe for significant development and offers promising opportunities for substantial progress. Some of these opportunities have purely intellectual interest irrespective of their ultimate practical consequences; others involve changed modes of educational delivery which could have far-reaching implications for improving our educational system. But all of them represent substantive challenges. Hence, the essential prerequisite for progress is the adequate investment of first-rate talent rather than the mere deployment of new technology.

The challenges fall squarely within the university's domain since the university is supposed to play a central educational role and possesses a pool of talent capable of innovative leadership. Present institutional attitudes and structural conditions mitigate, however, against a serious university role in educational innovation and excellence. Nevertheless, it is possible to suggest concrete proposals for modifying the situation so as to channel talent in the university toward fruitful work aimed at the advancement of education. In fact, existing precedents suggest that such proposals could be implemented in practice.

The challenges are so significant that there has been discussion about the prospects of an educational revolution. In addition, the opportunities for progress seem realistic and practical, both technologically and institutionally. Under these conditions, it would behoove the university not to sit complacently on the sidelines, but to play a leading educational role at the center of the stage.

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