per hectare would represent only nine-tenths of 1 percent of the total. This suggests a remarkable ability of these undisturbed systems to entrap and hold nutrients. However, if these calculations were based on actual amounts of calcium circulated each year rather than on the total, the percentage losses would be higher.

On its completion, the Hubbard Brook study will have yielded estimates, for individual elements, of many of the parameters and flux rates represented in the nutrient cycle shown in Fig. 1. These data will increase our understanding of fundamental nutrient relationships of undisturbed northern hardwood forests, and they will provide baseline information from which we can judge the effects on nutrient cycling of such practices as cutting, burning, and the application of pesticides.

Studies similar to these at Hubbard Brook could be established elsewhere in the United States. There are thousands of gaged watersheds operated by private and public interests (*17*), and some of these must meet the proposed requirements. On selected watersheds, cooperative studies could be made by the agencies or organizations controlling the watershed and university-based investigators interested in biogeochemical cycling. Just such cooperation, between federal agencies and universities, has been urged by the Task Group on Coordinated Water Resources Research (*21*).

Cooperative studies of this type have the advantage of providing a useful exchange of ideas between scientists in diverse fields who are working on the same ecosystem. The studies would provide a larger yield of information on a single system, the prospect of new concepts arising from the available information, and a greater scientific yield per dollar invested. Finally, cooperative studies would make available, for interpretation from the standpoint of nutrient cycling, an invaluable record of past hydrologic performance and, in some cases, of the responses of watersheds to experimental manipulation.

Conclusion

The small-watershed approach to problems of nutrient cycling has these advantages. (i) The small watershed is a natural unit of suitable size for intensive study of nutrient cycling at the ecosystem level. (ii) It provides a means of reducing to a minimum, or virtually eliminating, the effect of the difficult-to-measure variables of geologic input and nutrient losses in deep seepage. Control of these variables makes possible accurate measurement of nutrient input and output (erosion) and therefore establishes the relationship of the smaller ecosystem to the larger biospheric cycles. (iii) The small-watershed approach provides a method whereby such important parameters as nutrient release from minerals (weathering) and annual nutrient budgets may be calculated. (iv) It provides a means of studying the interrelationships between the biota and the hydrologic cycle, various nutrient cycles, and energy flow in a single system. (v) Finally, with the small-watershed system we can test the effect of various land-management practices or environmental pollutants on nutrient cycling in natural systems.

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Where Is Biology Taking Us?

Robert S. Morison

Others in this symposium (*1*) have described the expected improvement in our knowledge of perception, cognition, and learning, and have shown how these improvements can be expected to facilitate the educational process. It remains for me to try to identify some of the long-term practical consequences of these trends, so that we can prepare ourselves to exploit the advantages and minimize the dangers which accompany any advance in knowledge or technique. As formal education improves in effectiveness, it seems natural to suppose that its public image will continue to be enhanced. We in the United States have always held institutionalized education in high respect and, second only to our Soviet friends, have looked to it to solve all manner of individual and social evils. As it becomes more and more capable of actually doing so, its prestige must necessarily continue to increase concomitantly. What, then, are the probable consequences of the increased prestige of institutionalized education? No doubt there will be a considerable number, but I should like to look particularly at its effect on more traditional ways of transmitting accumulated experience to a new generation and to lay before you my reasons for believing that, as public recognition of formal education continues to rise,

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the prestige and influence of the family will continue to decline. As you will see, many if not all of the reasons have a strong biological cast. Whatever the reasons, if the conclusion is approximately correct, we would do well to try to predict and prepare for the consequences—some of which will be of biological, and all of which will be of great psychological and sociological, importance.

The principal reasons for expecting a decline in the prestige of the family may be briefly listed as follows.

1) The family, which is a fine mechanism for transmitting conventional wisdom in a relatively static society, is relatively poor at assimilating and transmitting new knowledge essential to survival in a rapidly moving world.

2) Growing awareness of the population problem and of human genetics weakens the prestige of the family as the basic unit of human reproduction.

3) Increasing knowledge of the plasticity of the human nervous system in early life will encourage further invasion of the home in the name of ensuring equality of opportunity.

Let us now explore each one of these propositions a little more fully.

Inadequacy of the Family as a Transmitter of Knowledge

Survival in the modern world depends on a rapid mastery of new knowledge. One of the clearest examples, and a nice biological one at that, is to be found in the production of food. By and large, the most successful nations today are those that have conscientiously applied modern biological knowledge to the raising of food. The invention of the spinning jenny made such a difference in the social and economic life of Western Europe that, ever since, we have been taught to think of the industrial revolution in terms of the dark satanic mills of the 19th century and the spotless, brightly lighted production lines of the 20th. But none of this would have been possible if agriculture hadn't been made more productive at the same time. In recent years the rate of production per man-hour has been increasing more rapidly in agriculture than in conventional industry. Ironically enough, it appears that the continuing backwardness of most Communist countries, when measured in terms of standard of living, has been due primarily to a failure to assimilate modern agricultural practices—partly for doctrinal reasons, and partly because of simple errors in planning.

When we shift our view from the survival of nations to the survival of the individual farmer, the principle is the same, but the poignancy of the situation becomes much clearer. The individual farmer who fails to keep up with the flow of new knowledge is out. In my own state of New York, the dairy business illustrates the trend. In 1930 the number of individual dairy farms reached a peak of 70,000. In 1964 the number had fallen to 36,000, and it is still declining rapidly. Milk production has nevertheless increased by nearly 50 percent. To be sure, individual farms are larger in terms of acres, but the number of men employed per farm has remained relatively constant, more constant than anything else in the dairy business.

One obvious social consequence of this change has been the heartache of 35,000 farmers who have had to admit defeat, suffer foreclosure, or sell out just ahead of the sheriff. Another has been the growing recognition of the importance of new knowledge and its rapid assimilation. Farming is highly competitive and operates on a very close margin. In recent years the production of broilers has declined very sharply in New York State simply because New York can't compete with states farther south in such matters as the cost of heating the chicken houses. In circumstances such as these, a farmer survives only if he keeps abreast of a mass of rapidly changing biological knowledge and of the even more unpredictable shifts in economic trends. The source of such knowledge for most farmers is the land-grant college or university and its network of extension agents. Consequently, the rural community in the United States has developed a healthy respect for scientific knowledge and the institutions which produce and promulgate it.

Inevitably, the prestige of more traditional repositories of knowledge and know-how has declined. Of these changes, the change in status of the family is perhaps the most important. The young boy or girl on the farm no longer looks to mother to learn about the setting of hens or to father to learn how to plow, fertilize, and harvest; instead he joins a 4-H club to learn about inbred and hybrid strains, antibiotics, hormones, and artificial insemination.

Farming provides but one example; expertise has replaced conventional wisdom in an ever-widening circle of human affairs. The trend began, of course, a long time ago and became particularly noticeable in this country at the height of the massive immigration from Europe. Observers of the social consequence of this movement have pointed out that the low estate of fathers in the United States can be traced in large part to the fact that the conventional wisdom of the immigrant European peasant was of little use to his children in their effort to adjust to a new world. By now, this inadequacy of immigrant fathers has lowered the status of almost all males over 35, since the New World is no longer a geographical concept but a chronological one. A similar loss of status is found in the scientifically based professions, notably in medicine, where the senior member of the hospital staff is no longer the court of last resort simply because he has accumulated the most experience. In some ways the young man who has just finished his residency has the most, or at least the most relevant, experience because he has been the most fully trained in new and more penetrating methods of seeing, hearing, and smelling.

Particular interest attaches to the status of what might be called moral wisdom in this rapidly changing world. In earlier times the repositories of knowledge, wisdom, and morals were inextricably intertwined. The high priests of the early riverine societies were the astronomers, the biologists, the philosophers, the lawyers, and the religious leaders, all wrapped into one. To a large extent, scientific and theological knowledge coincided. The rapid growth of scientific knowledge in our own time has resulted in a greater and greater gulf between natural and theological knowledge and a considerable decline in interest in the latter. Ethics and morality occupy an uneasy position somewhere in between.

Although it is customary in all ages to throw up one's hands in horror over declines in standards of behavior, the astonishing thing is that the decline in respect for fathers, mothers, and priests as repositories of expert scientific knowledge has not been accompanied by more of a decline in respect for their moral influences. As compared to our views on the nature of matter, the origin of the seasons, the control of the weather, and even on the creation and nature of man him-

self, our views on private property, murder, rape, and adultery have changed very little since the time of Moses.

I suggest that we may be approaching the end of this dualism. There are several reasons for believing that we can no longer keep our system of moral values and our system of scientific expertise in separate water-tight compartments. Perhaps most important is the fact that science, and especially biological science, has produced evidence to reinforce some ancient exhortations and weaken the hold of others, and has invented, or at least called attention to the significance of, an entirely new range of good and bad behavior.

To take a perhaps morally trivial but practically very important example of the first of these points, the Surgeon General's report contains far more and far better reasons for not smoking than all the exhortations of the Epworth League put together. Admittedly, the statistics do not yet support the notion that appeals to scientific analysis will be any more effective as guides to right conduct than appeals to divine revelation or parental authority have been in the past. So far, unfortunately, it is easier to show how the progress of knowledge weakens the older sanctions than to demonstrate its ability to establish new ones.

Nevertheless, it seems reasonable to expect that, however slowly, we will increasingly look to careful evaluation of evidence on outcomes of alternative courses of action as guides to right conduct. Insofar as the family is unable to assimilate and transmit such evidence it will continue to lose its already dwindling influence in the area of morals and ethics.

Let us turn then to our second point, the impact of biological knowledge on the concept of the family as the unit of human reproduction. No longer can a mother and father take satisfaction in unrestricted reproduction as the straightforward fulfilling of God's injunction to go forth and multiply. The evidence is convincing that, beyond a certain point, reproduction is not a social good but an overwhelming social evil.

The father of a large family must increasingly exchange the swelling pride of the *pater familias* for an embarrassed giggle over his carelessness or ineptitude.

Even if we admit in principle, as most of us do, that some families ought to have more children than others, it is not easy to specify the numbers in particular cases. For society as a whole it is not too difficult, perhaps, to arrive at some quantitative figure for the rate above which a population curve should not rise. For the individual, the problem is far more complicated, since, before he can settle the quantitative question, he must consider some very difficult qualitative questions and make some difficult value judgments as well.

Even if a government decides that the average family should consist of 2.5 children, the ultimate social decisions must emerge as the sum of a very large number of individual decisions. The presumption is that families with "good genes," a mother and father skilled in raising children, and sufficient money to sustain a good standard of living but not so much as to spoil or corrupt their children should have more children than families that don't enjoy these advantages. But who is to say what are the good genes or the most suitable child-rearing practices, and who will weigh out just the right amount of money? Even the purely biological considerations are not simple. Perhaps the easiest cases are the clearly negative ones. For example, a known carrier of a more or less fully expressed dominant defect as disastrous as Huntington's chorea will probably have little difficulty electing to forgo the raising of natural offspring. But what about the unusually talented who carry a recessive gene for something like pancreatic fibrosis or sickle-cell anemia? If they marry another carrier the chances are 1 to 4 that any children they have will exhibit the defect. How is this to be balanced against the chances of producing unusually capable offspring? If the carriers try to avoid the dilemma by identifying noncarriers as prospective mates (and the progress of science makes such identification increasingly possible), they will merely contribute to spreading the defect ever more widely through society, so that succeeding generations of carriers will find it ever more difficult to find suitable mates.

It is considerations like this that have led some very eminent geneticists to suggest abandoning the concept of the family as the unit of human reproduction in order to follow theoretically more suitable models derived from animal husbandry. Even more dramatic are the possibilities now being conjured up of eliminating defects and producing unimaginable virtues by tinkering with the genetic code itself. Even though it seems unlikely that a substantial number of people will shortly abandon classical methods of reproduction for the models derived from animal husbandry or bacterial transformation, it is undeniable that the progress of science is bringing about a growing separation between the phenomena associated with sexual attraction and those involving reproduction per se. Much of the conventional moral apparatus of almost all societies has, however, been based on the assumption of an extremely close tie between the two. Clearly, we are in for some big changes, the social consequences of which are not easy to see.

Much attention has of course been given to presumed changes in the premarital habits of our adolescent and college populations, though there is relatively little evidence as to how extensive these changes really are. Much more important, it seems to me, are the changes which may come in the institution of the family if sexual behavior and reproduction become completely separated from one another. Many of us who have become impatient with the Roman Catholic church for the deliberate way in which it has approached the population problem must sympathize with the reasons for its reluctance. Although one has noticed a tendency to play down the purely theological aspects, the problem for the church is still based on a reluctance to abandon the natural-law position that the point of sex is reproduction. Once sex and reproduction are separated, society will have to struggle on the one hand with defining the nature of interpersonal relationships which have no long-term social point other than the satisfaction of the individuals concerned; on the other hand, it will have to seek new ways to ensure reasonable care for infants and children in an emotional atmosphere which lacks biological reinforcement through basic sexual and parental drives. Although there are plenty of successful foster mothers and fathers, the application of the principle of foster homes on a much wider scale than the present one would seem to require a far higher degree of moral sophistication than the average person is likely to possess. It may, for example, be only the unusual husband who will feel

very warmly about the children that result from the artificial insemination of his wife.

As pointed out above, a third type of assault on the integrity and authority of the family is almost certain to grow out of our increasing knowledge of the biology and psychology of infancy and early childhood. Although relatively little is known in this area with any real certainty, all the evidence we have points to the importance for future development of influences brought to bear during the first 5 or 6 years of life. These are the years which the child ordinarily spends in the bosom of his family, and evidence is accumulating that it is this fact that is primarily responsible for the relative fixity of the socioeconomic class structure of a country like the United States.

Just as a wider appreciation of the science of genetics has made a pleasant 18th-century fantasy of the stirring phrase "all men are created equal," growing knowledge of the plasticity of the human nervous system, of critical periods in development, and of the phenomena of imprinting and releasing as well as of conditioning and stimulus-response learning has made it quite clear that it is idle to talk of a society of equal opportunity as long as that society abandons its newcomers solely to their families for their most impressionable years. The institution of such programs as Head Start testifies to the growing awareness that society must in effect invade the sanctity, or at least usurp some prerogatives, of the home if it is to assure equal opportunity for all. As society itself becomes more complex and demands an even higher standard of emotional and intellectual competence from all its members, it seems increasingly unlikely that at any level it can rely exclusively on the haphazard educational procedures provided by home environments during the most impressionable first 6 years of life.

I am not advocating that the family be abolished. I am merely pointing out that some of its functions have already been taken over by other social agencies and that more are likely to follow.

We have already accepted, with only a minimum of protest, the principle that children who don't get enough food at home should be properly fed at school (though it must be admitted that this social advance was facilitated by the fact that many normally Republican states were at the time producing excessive amounts of grain and dairy products). There is still some difficulty in providing sex education in school for the children of parents too dogmatic or too squeamish to provide it at home, but the opposition is crumbling. Somewhat curiously, the major public opposition to invasion of the home by the State seems to center at present on the right of the parents to decide whether or not their children shall have dental caries.

While on the subject of idiosyncratic defenses of parental prerogatives, I can't forbear mentioning an old friend and former boss of mine, now a highly placed official in the Great Society, who used to lecture the Scarsdale School Board on the dangers to individual liberty inherent in courses in driver education.

As evidence accumulates that infants who have mobiles floating over their cribs develop hand-eye coordination faster, and that those who have books at home learn to read earlier, than those who don't have these amenities, it seems inevitable that society will provide aids to development, just as it now provides vaccination and school lunches.

Certain other functions of the family—notably the maintenance of a reasonably stable emotional atmosphere, with some more or less regularly available mother figure for the child to cling to in time of stress—are likely to be most effectively and economically provided, for some time to come, by the family as we have traditionally known it. Presumably, some inventiveness will be needed to preserve and, if possible, enhance these roles while allowing for the inevitable decline of familial function in other areas.

Although I believe it to be a matter of great importance that those functions which the family can perform better than any other social mechanism be defined and strengthened, it is not my purpose to propose how this may be done. What is equally important is for society in general to recognize what is happening and to become more conscious of the need to develop a new mechanism for supplying the individual rewards and satisfactions, and for strengthening the ties between human beings, which used to be provided almost wholly through family life.

It is not very hard to believe that, on balance, the expected erosion of parental responsibility in certain areas will be good for the child. It is less easy to be sure of the effect on the parents. The principal fear of those who would keep society, or the even more frightening State, out of the home is that too much control of growth and development will reduce the freedom of the individual and, in the long run, produce a colorless, conformist society. I have relatively few worries on this score. Education has never turned out the exact product the educators had in mind, and I am reasonably confident that it never will. To use a phrase taught me by L. J. Henderson, "it is an induction from experience" that it is the most educated people in a society who are the least conformist and the most innovative. The Reformation was sparked by highly trained monks like Luther and Calvin, and, in our own time, the leaders of the Russian revolution were drawn from the intelligentsia of the old regime. Conversely, those who worry about the conformity of the organization man should reflect that the greatest conformist of all history has been the unlettered peasant, whose ways are much the same on every continent and have scarcely changed in 4000 years.

No, the real point of bringing education into the home at the earliest possible age is not to induce conformity but to cultivate the plasticity —the almost infinite adaptability—of the human nervous system. Deprived of appropriate sensory inputs at an early age, it may never realize more than a fraction of its capacity. Stereotyped behavior is the result not of training but of deprivation. It is hard to see how enriching the environment and increasing the contacts of young children can do other than increase their capacity for intelligent choices later in life and thus free them from both external and internal constraints that normally limit personal freedom.

The difficulties that are likely to arise are of quite a different sort and would, in the first instance, be visible in the parents. Insofar as parents are relieved of responsibility for their children and the functions of the family become diffused throughout society at large, the parents are likely to feel less significant in the scheme of things. It is now widely noted that it is in the so-called advanced countries,

where the problems of immediate survival have largely been solved, that men are least convinced that life has any real point. Lacking the spur of hazards to their own lives, many people find a feeling of significance in their role as parents. As a personal example, let me note that I have not felt seriously anxious in an airplane since my children reached the age at which they could quite obviously take care of themselves. One way of interpreting this phenomenon is to say that life means somewhat less to me now that I recognize that my continued existence is less important to my children.

If we are right in predicting that, in the future, almost everyone will have fewer children and that an increasing number of people, for sound genetic reasons, will have none at all, and if, furthermore, we are right in predicting that society will take a larger share of responsibility for the welfare of the infants and children who do manage to get born, it seems inevitable that larger and larger numbers of people will be deprived of the pride of parenthood and that by so much will their sense of worth be diminished.

Alternatives

If all this is even approximately true, it would seem essential to set about devising substitutes or sublimations. Somehow people must be made to expand their sense of loyalty and responsibility to include a larger share of the human race.

Such an expansion of responsibility is pressingly important on other grounds, for, as I hinted above, the advance of biological knowledge has created new misdemeanors if it has not induced new sins. As Waddington (*2*) and others have shown, it is no longer sufficient to assess our behavior in terms of its results on those immediately around us. Much of what we do has some sort of numerical probability of injuring someone else we have never seen—on another continent, perhaps, or even in a generation yet unborn. As we sum the increasing probabilities of these adversities we find life growing intolerable for a large share of the human race. We are thus becoming statistically responsible for the purity of the air we breath, the water we drink, and the safety of the highways we drive on; but, so far, it is hard for us to feel a statistic. And, without the proper feeling, few of us can be moved to change our behavior. Perhaps the most important social consequence to be hoped for from our increase in biological knowledge is development of the ability to feel statistical meaning so keenly that we will modify our actions in adaptive directions.

Maybe it will take some drastic biological mutation, but, when we do develop the ability to feel statistics, we will give up smoking when we read the Surgeon General's report, feel as pleased with ourselves for *not* having children as we now feel for having them, and be delighted to get together with our fellows to fluoridate our water or to cease pouring incompletely burned hydrocarbons into our atmosphere.

What can we do short of the proposed drastic mutation, which in any case will come too late? Clearly, we must turn to the more rapid way of changing human behavior and rely on cultural rather than biological evolution. Here we find that one of the very real difficulties in reaching a general solution of the human predicament lies in the inescapable biological paradox that we experience life as individuals while in the long run we survive as members of society.

Our homeostatic apparatus, which has come down to us from a former generation, is geared to producing intensely personal sensations of hunger, pain, fear, and rage whenever our existence as individuals is threatened. Our dependence on a social context is less clearly defined in immediate consciousness. At the level of social organization represented by the family, certain basic attractions and responsibilities are built into our biological structure in the form of sexual and maternal love and a somewhat more uncertain and ambivalent sense of filial dependence.

As we go up from there through the village, the tribe, and the state to the comity of nations, the ties that bind derive less and less from instinctive patterns or immediate conscious sensations and more and more from inference and abstraction.

Society has therefore had to invent ways of coupling its needs to the emotional apparatus of the individual. Religion and art were two of the most important of such inventions. In an earlier time a large proportion of artistic production served a patriotic or religious (and, in consequence, a social and moral) purpose—for example, by making the individual feel in his bones the importance of dying for his country, or, at a higher and more abstract level, the mystical unity of the brotherhood of man as children of God.

Now we seem to face unprecedented needs for mobilizing all possible aids to help the individual perceive the needs of society at large and to identify himself with them. Not only have the social and economic developments of the last few centuries made everyone far more dependent on everyone else for the means of subsistence but, as I have tried to show, the responsibility for development of the individual personality, even at very early stages, is shifting from the family to society at large. Conversely, an increasing number of individuals must seek emotional security and a sense of significance in roles which greatly transcend the classic limits of family or village.

In view of these obvious and pressing needs it is certainly curious and probably rather frightening that so large a proportion of the artistic and literary community has elected to stand aside like a Greek chorus, chanting over and over again, "See the unhappy man who can do nothing other than endure the existential suffering forced on him by a hostile and malformed society."

These are not merely the thoughts of an unfeeling biologist striking out at random against another culture. A far more penetrating analysis of the state of modern literature and its impact on the university and intellectual world may be found in the recently published essays and lectures of one of the finest humanist critics of our time, Lionel Trilling. The principal message of these papers is quite explicitly that modern letters are oriented against society—not, as used to be the case, against a particular society, or a particular outmoded social norm, but against the very idea of society—in other words, against any society at all.

As a biologist, I find the predictable biological consequences of such an attitude terrifying.

Reference and Note

1. The lecture on which this article is based was my response to a request to speak on "predictable social consequences of changes in education which may be expected to grow out of advances in biological knowledge."
2. C. H. Waddington, *The Scientific Attitude* (Penguin, Harmondsworth, Middlesex, 1941).