# PROBLEMS IN THE APPLICATION OF SCIENCE EDUCATION TO NATIONAL DEVELOPMENT

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## ABSTRACT

Failure to make important distinctions between science and technology and failure to recognize science as a cultural form leads to school science inappropriate to national development. Although there are instances to show that science can have an important impact on technological growth, other examples show that science is not of necessity a precursor to technology. On occasion the application of science to technical problems may impede technological and hence economic development. In order for school science to have a desirable effect on technological and economic development, it is important to recognize science as a cultural form. Cultural theory, supported by recent evidence in the cognitive sciences, suggests that knowledge learned in particular social and cultural contexts, such as that of the school, remain applicable only under the cultural rules of that context. Knowledge so learned is not transferred to contexts where other rules of cognition apply. We possess insufficient knowledge about the cultural and social attributes of science and technological learning both in and outside the school to design school science curricula and methods which are demonstrably related to economic and technical development.

Introduction

Historically scientists and science educators have said their professional activities and institutions are important to national development. From the time of Francis Bacon to the present day, apologists of the scientific community have argued that science is a special activity with important economic, social, and political ramifications. They argue that education in the sciences spreads knowlege of and about science and provides the foundation for the practice of science in the populace. Thus, science education is the means to bringing the benefits of science to the community or nation.

The presumed benefits of science education fall into at least three categories. Economic, socio-cultural, and political. The economic benefits derive from the postulated relationship between science and technology. Those educated in science, even at very rudimentary levels, will become better producers because they will invent new technologies or better understand existing technology so as to adopt and adapt them for local use. Since technologies are the tools of production, science education should provide the people with the means to invent new technologies or adapt existing technologies to local conditions and increase national productivity and wealth.

The socio-cultural benefits of science education are closely linked to its hypothesized economic benefits. Proponents presume that once the members of a populace become aware of the very special character of scientific knowledge, they will cease to be superstitious and will give up old beliefs and customs. They will live together more harmoniously because they will give up fear of witchcraft and other forms of "irrational" social control. Giving up old customs should allow people to use new scientifically based practices and technologies in health and agriculture. People would use agricultural and health practices based on solid evidence rather than folklore. More than that, they will be able to work differently in new industrial, agricultural and bureaucratic settings. They will be better, more reliable workers. They will see the advantages of modern, "rational" modes of bureaucratic and professional organization, managed according to scientific principles, and go about their work with ever increasing efficiency.

Both the economic and social benefits of science education are presumed to lead to political outcomes. If people are led to adopt behavior based on rational knowledge, prejudice in the society will be reduced along with racial, religious and ethnic conflict. Furthermore, people will be richer - the economic pie will be bigger - and there will be less cause to engage in conflict. Because the populace would be more rational and less susceptible to emotional, illogical appeals, policy could be decided through rational political debate in parliamentary democracies. The people would be able to see through the effects of charisma and other accouterments of irrational leadership. They would not blindly follow emotional appeals. Leadership itself would be better able to see the best road to social and economic success.

The assertion of the importance of science and education to national development is based on the important assumption that the problems of mankind are a result of a lack of knowledge. The roots of poverty and disease are ignorance. Because education in general and science education in particular, are thought to instill in the people processes for obtaining and using knowledge, proponents for the scientific community claim science education in the schools is an important means of national economic, social, and political strength.

While accepting the notion that at times and in some circumstances the development of science education in the schools can have an important impact on the course of national development,[1] the argument presented in this paper is that in many cases it does not have such an impact. By and large scientists and educators give inadequate attention to the nature of science as a cultural artifact and schools as cultural and social institutions. Science learned in schools is most often learned as a cultural form in much the same way as anthropologists learn about cultures other than their own.

Educators, policy makers, scientists, and others often fail to make important distinctions between science and technology without a clear picture of how the two are related in the solution of the many varieties of technical problems people face. It is naturally assumed that science is directly and causally related to technical development at all levels of human enterprise. This assumption is dubious.

Many educators and scientists have not made complete analysis of the cultural components of science and schools nor have they made important distinctions between science and technology. As a result curricula and educational methods are inappropriately designed for national development. They do not maximize the value of school learning to the solution of problems of productivity, health, and social welfare.

Definitions:

Science and Technology

For many years now scientists and science educators have been called upon to develop curricula and methods for teaching science in the schools. It is important, therefore, to have an idea of what these professionals talk about when they talk about science.

One should be aware that there is no single universally accepted and precise definition of "science". Scientists do many different kinds of activities and can be quite creative in their work. The processes of creativity are poorly understood. Nevertheless, it is clear that when members of the scientific community talk about science, the meaning they attach to the word is different than colloquial understanding. The following is an attempt to provide a concise and generally acceptable definition.

Note that in the following discussion I will make some rather sharp distinctions between science and technology.

Science, in the broadest sense of the term, is the elaboration of models or theoretical constructs to explain the behaviour of nature. In this sense, there are many different "sciences" - different collections of processes, rules and knowledge bases for gathering information and processing it into verifiable knowledge.

In a narrower and more professional definition, science is a particular epistemological pattern or means of elaborating materialist theories or idealized models to explain the behaviour of nature. In the sense that it is used here, the practitioners of science rely heavily on controlled experiments and the testing of the predictive value of their theories and models. Where experiment is impossible or difficult, scientists still demand that data fit closely with theoretical explanations as verification of theory. In science, a high value is placed on the use of measurement and numerical analysis for the verification and validation of information. A part of the epistemological system is a set of logical constructs, principles of choice, and descriptive statements, which have developed over the years. Examples of these categories are the conservation laws, parsimony of argument, and special relativity, respectively.

We must not forget, however, that science is also an occupation - a highly professionalized occupation at that. Organizations and institutions of the occupation support the training and work of scientists. They allow the occupation to define what is legitimate scientific activity and who are legitimate scientists.

Bear in mind that in most countries, scientists and science educators - members of the professional community of scientists - are called upon to make curricula and develop teaching strategies for science in the schools.

It is important to keep in mind the difference between the narrower "technical" definition of science and the more colloquial definition which is something akin to clever thought or to the use of logic. All people think. All people observe, and get things done by trial and error. All people use logic and are clever and creative in marvelous ways. But, these are not sufficient to fall within the realm of science. The fact that there may be great wisdom, some great <u>practical</u> wisdom, in folklore does not make it science or scientific in the sense used here.

(Science is also more than a collection of skills. Animals are very good at observation. They also learn by trial and error. Communication - very effective communication is a characteristic of many animals. In the absence of the well defined epistemology hinted at here, the animals cannot be scientific).

Technology, on the other hand, is an entirely different matter. Technology is designing, constructing, maintaining processes, tools, and goods, for human use. Technology, even in its linguistic roots, implies elements of art, design, craft and creativity in manipulating the physical world.

Note also that technology has its own separate occupational structure. Technologists are trained in separate institutions - schools of engineering as opposed to departments of physics, for example. At the level of craftsmen and technicians they have a different range of organizations - unions as well as professional organizations. Because of the economic value of technical knowledge, the technological occupation maintains institutions and organizations for providing patents, industrial secrecy, and sale and transfer of technology. There are in contrast to the mechanisms for the explicit sharing of scientific knowledge.

Although it is often said that science leads to technology, it is often the case that technology can occur without a science at all to back it up. Navigation among the Puluwat in the Pacific, for example, is a highly developed art (i.e. technology) which involves close observation of the sea and the sky. But as Gladwin makes clear in his description, <u>East is a Big Bird</u> (1970), the task is almost entirely empirical and the explanatory system not highly developed, while the technical systems and logic and the mnemonics to remember them are very elaborate indeed.

High technologies in Africa have developed for the smelting of metals - iron and steel, brass, gold and silver. Leather tanning and cloth dying were developed to a high degree centuries ago - long before the invasions of the Europeans who invaded in the name of civilization and before the notion of science as we know it came to be.

Even less of a knowledge base is necessary to use technology in routine ways. We can operate machines and tools and follow procedures without knowing why - only knowing that what we do works. The operators of word processing machines require little notion of the scientific underpinnings of computer operation and most, in fact have none. The same is true of typists and typewriters, automobile drivers and automobiles, seamstresses and tailors and electric sewing machines, and anyone who has ever followed a compass without knowing what magnetism is or how it works.

Science Education

Science education is taken to mean specifically the teaching of science subjects in schools. The science subjects are typically taught under rubrics of biology, chemistry, physics, general science, agricultural science, physical science, unified or integrated science, elementary school science, and so forth. The definition used here includes a formal curriculum incorporating teachers, textbooks, laboratory exercises (both discovery and non-discovery), problems sets, and so forth. It may not be the case that a particular educational system under consideration has all of the accouterments of a desirable state of science education in hand. Significant numbers of trained teachers may be lacking. Textbooks may be out of date and laboratory facilities sparse. Even under adverse conditions, people can still teach science in schools.

Informal science education activities such as science clubs and so forth do not constitute science education as defined in this paper. A system with a few non-curricular science groups, but with no formal curricular structure, is regarded as not having science education.

National Development

Nations are complex systems and debates rage about what constitutes development and how one measures it. The definition I postulate here takes into account both social and economic features of national development. Development here is to be taken to mean: 1) generally increasing national and personal income in "real" terms when both market economy and subsistence production are taken into account; 2) general improvement in moving toward an equitable distribution of income and the concomitant improvement and spread of health, education and welfare services; 3) general improvement in productive technologies and the spread of technological benefits to all income groups; 4) the establishment and maintenance of civil liberties and broadly defined democratic participation (Note this is not the same as parliamentary democracy); 5) Finally, development entails a cultural elaboration and adaptation based on the integrity of past forms.

Given the complexity and fluid state of the world in the present, the past, and presumably in the future, it seems impossible to define a particular state of development. Rather, development is a process. The fundamental issues are whether or not nations and societies are progressing, stagnating, or regressing according to the norms outlined above.

Science Education and National Development:

If education in the sciences is to have any impact on the course of development in the nations of the world, then the populace must be able to transfer what they learn in schools to what they do outside the school in the world of family, work, play. What they come to know in school must have impact on what they do elsewhere.

While there is a long history to the claim that learining in the sciences has an important impact in the five areas of national development outlined above, it is not clear that science knowledge, let alone science education, in itself improves life in the moral and political arenas. There is no way of making a definitive judgement that the scientifically powerful nations are more or less just or fair in their political and cultural behavior. Although many nations with advanced scientific capabilities and institutions have all achieved some wonderful political and social advantages for their populace, many have committed horrible atrocities - some have attempted genocide.

Because of the difficulty in sorting out moral and evaluative issues from scientific ones in national political and social life, the argument here will not address the influence of science education on politics or culture. Rather it will focus on increasing economic performance through the invention and improvement of technology and the improved economic performance of workers using new or improved technologies.

Does Science and Science Education Contribute to Economic Growth?

Many in the past have postulated the argument that science will lead to technological advancement. In the 17th century Francis Bacon, perhaps the best known early proponent of the scientific revolution, described what he felt to be the power of the new inductive and experimental science in generating new and valid knowledge. In his utopia New Atlantis, Bacon describes the presumed benefits of the New Science when applied to the needs of commerce and the state.

Others followed in the same vein. In the 18th century the Frenchman D'Alembert wrote of the importance of science to the development of the society and the economy. In his Preliminary Discourse to the Encyclopedia of Diderot (1751) he described the important impact of science on technology, politics and culture. But, on closer reading, it becomes clear that D'Alembert by and large praises the potential value of science. He is making a claim that science would contribute to technology if properly supported. For example, D'Alembert waxes poetic about the importance of magnets to navigation and the wonderful problems they pose to understanding (p. 23). He proposes the scientific study of an important technology that had been in use for several hundreds of years. Elsewhere in the document one gets the impression that D'Alembert had to search and stretch to find technological examples to demonstrate the power of science.

What makes D'Alembert's work relevant is that it was the introduction to an encyclopedia replete with the achievements of technology: technology that was beginning to generate what we now call the Industrial Revolution. D'Alembert (and others) could not clearly articulate the contributions of their science to the then existing technology. Indeed, even today, it is not clear at all that science had any direct impact on technological development until the late 19th century when chemistry began to play an important and direct role in the dye industry. Perhaps the lightning rod was the only technology deriving directly from a scientific theory before that time.[2]

Clearly a useful technology often begs for explanation to enhance the technology after it is developed. The desire to understand glass and light led to the science of optics, steam technology led to the development of thermodynamics, 18th and 19th century industrial development, particularly in dye manufacturing led to a formal science of chemistry.

More recent examples are somewhat more ambiguous. A full explanation of the triode and later of the transistor could not be elaborated until these devices were invented. Yet important science was known by the inventors of these devices beforehand and the application of science after the invention dramatically improved both technologies.

The fact that the interaction of science and technology has led to improved technology and production in some instances does not mean that this is universally the case. In fact, there are other important instances where the application of science to technological problems has in fact impeded technical and hence economic growth. A very clear example is that of

American millwrights and French hydraulic engineers in the 19th century. Their story is told by Edwin T. Layton of the University of Minnesota in his article "Millwrights and Engineers, Science, Social Roles, and the Evolution of the Turbine In America" (1978).

American millwrights were essentially itinerant builders of water mills. Many were self-taught and had little, if any, formal training. The extent of their knowledge of mechanics was the rudiments of Newtonian physics (the third law, particularly). The Americans were unschooled in hydrodynamics. Increased efficiency was achieved almost exclusively by trial and error. Unschooled in the sciences of the times, they used whatever inexpensive materials were available. For the casings, turbine rotors, etc, they used simple designs made of roughly cast iron. Judgements were made on the effectiveness of the product rather than the elegance of design or adherence to known scientific principles.

The French, on the other hand, insisted on the application of state of the art scientific knowledge to the building of their mills. Being an advanced nation, they had well-developed institutional mechanisms for ensuring the use of science in their water technology. Mills were designed by hydraulic engineers who, before beginning construction, would formally present their designs to their colleagues in professional presentations. Designs were expected to conform to the scientifically accepted principles of hydrodynamics of the time. Unfortunately, the science of hydrodynamics of the early 19th century did not yet include the principle of laminar flow.[3] French designs specified that the surfaces over which water flowed would have to be highly polished. According to existing theory the highly polished metal would reduce friction between the water and the turbine interior surfaces. Greater energy efficiency was thought to result. The French went to great expense to obtain high quality steel and to polish the interiors of turbines before installation.

At the time, the French engineers "knew" this extra expense and effort to be necessary. We now know it to be unnecessary. The end result was that the American turbines, built along technological and not scientific principles, achieved high efficiencies and performance at much less cost than the French models. Indeed, if the United States had followed the French mode of design and construction, the provision of energy for the agricultural and industrial exploitation of rural areas would have been much delayed until the discovery of laminar flow in hydrodynamics.

In this story of millwrights and engineers we see the interaction between occupational forms, economic and social circumstances, and the use of knowledge. The French formalistic approach to knowledge and its use had a lot to do with the existence of specific institutions for the development of knowledge. The American approach resulted from a relative lack of such institutions and isolation from the centers of knowledge. For occupational reasons the French engineers had to be "correct" in the sense of having their technology conform to existing scientific beliefs (which at the time was not belief, but knowledge). Apparently the owners of capital could afford the luxury of French correctness.

Note also the implicit French assumption that scientific principles when applied to technology de facto would lead to technological effectiveness. Clearly the Americans showed otherwise.

For the Americans, the freedom from the formalities of professionally defined science led to improved technology as it developed at the point of use. The technical knowledge, not based on the existing scientific principles, did not have the benefit of institutional review by peers of experts. Hence, the practitioners were not hampered by incomplete or erroneous theories and models, nor the constraints of formal professional organizations.

Finally note that the Americans could have followed the French example. Capitalists and state governments could have insisted that French experts be hired. The French-built mills would have worked, too. However, they would have been far more costly and development would have been constrained because of increased energy and manufacturing costs.[4]

Later, as the United States became more industrialized, and both French and American engineers and millwrights came to understand better the dynamics of water, formal science was increasingly applied to the design and construction of water turbines on both sides of the Atlantic.

The story illustrates an important issue in considering the development of science for the schools. Clearly the American millwrights were being scientific in their everyday work in their empirical attitude and approach to the problems at hand. The French, on the other hand, were being professionally scientific, placing high value on the formalities and institutional structures surrounding an accepted scientific knowledge base. In the end, the successful development of the most economically effective technology depended on a mode of approach at the point of technological use, rather than the possession of a scientific knowledge base and adherence to occupational norms. The knowledge gained was obtained from practice, not from formal learning settings.

While the story of the millwrights and engineers is from a past era, it illustrates a point that is still true. It remains true that the formalistic scientific approach to solving problems is not de facto the road to the most effective technology. There is still much incomplete knowledge in the agricultural, health, biological and earth sciences as well as the more abstract physical sciences. Much of the environment is poorly understood, and yet there are still rapid applications of scientifically based technology on a large scale without full understanding of the principles of environmental interaction. All too often we still follow the example of the 19th century French water engineers. These technologies, like pesticides, often provide short term gains - they work - but later generate unanticipated costs because they are incompletely understood.

There is no question that it would be a great loss to African Agriculture if the traditional technologies and knowledge of farming, were lost to the formal study of scientifically based agriculture in the schools. Clearly both are necessary. One example of endangered knowledge is knowledge of local indicator plants used by traditional farmers to guide planting cycles and land use.

There is no question that the science taught in schools by and large is formalistic and professionally oriented. Moreover, little distinction is made between science and technology and the technological efficacy of folk wisdom. Science tends to be taught qua science: emphasizing a set of skills and/or the philosophical basis out of which the sciences grew, rather than the technological questions of the world in which we live.

Another way of saying the same thing is that in most schools science is taught as a cultural form, which it is, but without helping students to understand how cultural attributes constrain the application of science to everday problems.

Science As a Cultural Form:

The fact that science is a cultural form is of profound importance to its teaching and learning. What is at stake is the extent to which knowledge can influence peoples daily and productive lives.

Clifford Geertz in his Interpretation of Culture (1973) helps us to fully understand the implications of the cultural attributes of an activity. Culture, he says is "a web of meaning enmeshing people's lives." The web is expressed in the accouterments which surround and are a part of living activities: modes of work; dress; language; dance; play. The meaning is implicit and of deep importance. Clothes, gestures, cars, books, music, all carrying meaning about class, personal preference, transient feelings, and mode of speech and work in addition to explicit information of a cognitive nature. Very clearly technologies have important cultural characteristics. For example, people in different cultures use wood saws differently.

But, thinking is an everyday activity. The "web of meaning" which defines our culture applies equally to the way we think as to the way we act. There is symbolic meaning to the way we view the world, what we know and the way we think about the world. These meanings are beyond explicit cognitive maps and collections of descriptive and analytic concepts and schema. The way that one thinks is part of one's definition of one's place in the universe and earthly society and one's affiliation with others in the society. For example, in some forms of Christianity thought has the same moral status as action. That is, despite thought occurring as a process in the individual mind, it has social meaning and import and is subject to cultural rules of use.

It is worth expanding on this notion. A characteristic of culture is that the rules of the culture are not necessarily obvious to its participants. Reactions to actions, things, and symbols are felt and responded to "automatically" and without explicit thought. For most Americans there is an immediate aversion to eating insects. There is no logic to the response. One simply experiences the aversion. It is simply there.

Consider, for example, the notion of what one could term "appropriateness of action". One aspect of culture is the definition of action as being appropriate to particular conditions. A cheer or whistle of approval is appropriate after a score by a favorite athletic team, not after a good homily in a High Anglican church. Moreover, it is the character of culture that the rules are subconsciously applied. When in church, few people have to think deliberately that they should not whistle.

More than action - for example, whistling or not whistling - is at issue. The arousal of feelings, thoughts, and memories are culturally allocated to specific settings in any society. Offices, farms, churches, health clinics are all places which arouse particular thoughts and feelings, often associated with rituals and often not appropriate to other places. (It is a consistent problem for the clergy that their congregations only think about God and being good in church and not outside the church). Funerals are explicit settings to allow people to ponder the meaning of life, mortality, and ultimate purposes. Lectures, symposia, and professional meetings allocate specific times to the formalization of occupational information and provide settings where informal shop talk is permitted.

In the above and many other imaginable circumstances, particular categories of thought as well as behavior are encouraged and others discouraged. That is not to say that people's minds don't wander (Galileo watched pendula in a church). As long as observable behavioral norms are adhered to, however, no one can catch the mental offender. It is the extreme power of culture that we all monitor ourselves to follow cultural patterns. We don't even think about whistling in church or going to an important business appointment without clothes. We generally don't use the wrong pattern of thinking at the wrong time.

In applying these notions to school, and in particular to "scientific thought" learned in school, one must regard the school as at least a well-defined ritualistic cultural setting. In some places the school is a ritualistic expression of an entirely different culture from that of the surrounding community. Schools are particular ritualistic of cultural settings where it is intended that children are taught to think in particular ways and not others; where they are rewarded and punished for thinking and talking about particular shorts of topics and not others; where they are encouraged to engage in particular forms of expressive behaviour and not others.

Under these conditions, evidence shows it is entirely possible in the school setting to master a kind of thinking and a whole range of concepts. skills, and capabilities which are appropriate to that setting without the faintest notion or ability to recognize their appropriateness or utility in other settings in life. It appears that when we formally learn science thinking, we informally learn the rules of appropriateness about when to think scientifically.

Again, we are not always aware that the rules exist or that we are applying them.

Recent work on preconceptions or alternative conceptions about science provides examples of how students revert to Aristotelian mechanics even when they have studied Newtonian mechanics. Further observation shows that when a student's observation about a particular phenomenon does not correspond to a prediction made from an "alternative conception" or common sense, students will often deny the source of evidence - the character of the experiment - rather than discovering the inconsistencies in their own informal theories (Champagne, 1984) (Linn, 1984).

These observations are not unlike those made by some of us who have taught students who will learn "evolution for the examination, but won't believe it" because of their strong attachment to religious belief. In some settings religious beliefs still prohibit believing that the solar system is heliocentric as opposed to geocentric. On a slightly different scale, interest in and attempted practice of ESP and astrology thrive in the "scientific cultures" of the industrial Northern Hemisphere despite the collected opposition of most of the formal scientific community.

In my own formal research, I have had the opportunity to discuss with scientists, traditional healers and others the phenomena of the persistence of alternative knowledge systems which contradict accepted scientific knowledge or sanctioned means of obtaining knowledge. In more than one instance people told me of their awareness (often after the fact) of their facility to move back and forth between internally consistent but mutually exclusive knowledge systems.[5] In cases of relevance to this paper these have been from materialist "science based" systems to what one might call "spiritual folk wisdom based systems".

In discussing the phenomena in differing contexts, one is struck with the ability of people to recognize the contradictions between their own personally held knowledge systems and to accept those differences as part of their particular living circumstances. In one exemplary interview, a non-Western university scientist told me how he and his colleagues recognized their ability to easily move from science based to traditional patterns of life. He said:

> It (the ability to shift cognitive patterns) is very interesting to us and we talk about it among ourselves in the university. When we are in our offices and laboratories we behave very scientifically. When we go home we make sure that the water is boiled for our babies. But when we put on our robes and go home to the villages and visit our parents and elders, we think very differently. It's not that we are behaving in a way to please them. It's that we are <u>thinking</u> differently (emphasis his).

In most cases and around most issues, there is not a great deal of psychic dissonance around differing individually held knowledge systems. It is when there is a confrontation with authority structures or with very deeply held symbolic beliefs of differing systems that dissonance can arise. For most people most of the time explicit differences between simultaneously held systems is not a serious problem even when it rises to the level of consciousness. It is possible to assign thought to particular contexts and explicitly hold it irrelevant to others. It is possible to say, "I will learn it for the exam, but I won't believe it." It is possible to consciously or sub-consciously shift knowledge systems like changing diskettes in one's personal computer.

Previous authors, Robin Horton (1966) and Yehuda Elkana (1978) and the Ghanaian Wiredu (1972) all commented on the ability of people to hold mutually exclusive knowledge systems. Horton called the process second order thinking and even attempted to establish the journal Second Order to further the study of comparative epistemology. (As far as I know only a few issues of the journal were published out of the University of Ife in Nigeria).) Jehuda Elkana elaborated on the notion of two-tier thinking during his presentations at the Boston Colloquia on the History and Philosophy of Science when he considered science as a cultural form.

It would be impertinent and wrong to attribute two-tier thinking only to people in Third World countries. It is a widely existing phenomenon in the United States and Europe. There is a shop just down Massachusetts Avenue from Harvard University in which the proprietor is an avowed witch. Many scientifically educated people - or at least many people who have had some science in their education - still accept as viable beliefs those which the establishment calls the occult.

A more emphatic example is provided by anthropologists who develop the ability to function professionally in differing epistemological systems as part of their cross-cultural work. The essence of anthropology is the attempt to immerse oneself in another people's system of thought, action, and symbolism and to attempt to re-interpret that system for those who use another system. To do so and to maintain their identity, anthropologists must formalize the mechanisms of second order thinking.[6]

The existence of what one might be call anthroplogical thought is relevant to understanding the phenomena of the persistence of alternative conceptions about nature, despite success in school science. Schools, as Glen Aikenhead (1984) has recently emphasized, "are social means for achieving social ends." People are in schools for many reasons besides the learning of cognitive structures. In most countries with a large a rural population, schools are the principal selection mechanism into the formal labor market and the world economic system. Schools are the way to get ahead. While it matters to policy makers and national economists that schools change the way people work in the rural areas, for most of those in schools, it doesn't matter whether or not the knowledge gained is useful in everyday life. For the family, what matters is that the student learns what the teacher teaches to get good grades or pass the exam. It also matters not to create disturbances and be punished or thrown out of school. It matters to become a lawyer, doctor, engineer, fireman, astronaut, sailor, pilot, or agricultural engineer. It matters to learn the rules of appropriateness about the knowledge one is learning. These rules are learned in a specific context around specific rituals and practices. They can be learned as an anthropologist learns them: that is, to serve some social function isolated from other functions which have a deeper significance for the individual or group. Particular kinds of epistemological systems, thus become cultural artifacts to be learned as such.

Science learned as a cultural artifact has little application outside the cultural context in which it is learned. Science learned in school is learned as science in school, not as science on the farm or in the health clinic or the garage.

The extent to which school learning is incorporated into life outside the classroom has much to do with the character of the school context in relation to the out-of-school context. It is when, for example, students in school link particular school activities to important non-school activities or work that school may have an impact on productive or social behavior in alternative cultural settings. It may be that it is when a student aspires to be a scientist and also learns that, in fact, scientists take care to apply formal school knowledge to specific out of school events that students practice the knowledge in their lives out of school. Given the fact that very few children become scientists, this probably happens in very few cases.

The problem is that we do not know how people learn out of school. We know little of the relationship between **what** science people know and the technology they practice in the variety of settings important to national development. We also do not know how the symbolism and cultural attributes of science learned in school affect its application and use.

If students are expected to use science in their technological lives, they must not only be taught about science, they must also be taught about technology as it is in their environment. Students must not only learn about combustion, they must also learn about the local blacksmith, automobile fitter or mechanic and what they do and know in their work. A comparison in the classroom could then take place where students could learn how what they know about science could improve the particular technologies they study.

If local "unschooled" craftsmen and technicians are competent and good at their work without a substantive science base, students must know this. But they must also be able to analyse instances where a further knowledge base would make specific differences. It is a travesty to simply say that a skilled craftsman would be better on the basis of having studied some school science.

As of yet we still do not have sufficient information about knowledge use in everyday productive settings to design materials and teach curricula explicitly relating science to technology. The work of Cole et al. (1971) provides an interesting starting point in Africa. The volume edited by Brokensha, Warren, and Oswald Werner Indigenous Knowledge Systems and Development (1980) also provides useful insights into the relationship between local technical practices and local knowledge systems. Gladwin's (1970) earlier cited book is another example of what might be done.

In general, the overwhelming emphasis in educationa research, particularly research on science education, has been devoted to the psychological processes which take place in the individual learner in the school context. Little has been done on group and contextual factors. The social function of the schools as mechanisms of acculturation, occupational preparation, custodial care, cultural assimilation or cultural diversity has profound impact on what science is learned, the way it is learned, and the use of science learning out of the school context. Much needs to be done in applying work like that of John Ogbu (1978), a Nigerian at the University of California, who has been studying the complexity of ethnic differences in the United States and how these complexities affect schooling.

Further information is required about the way that ple learn outside the school setting when they are in direct ntact with nature. Automobile mechanics, farmers, fishermen, nd adults caring for children all learn something about the biological and physical universe. What do they learn from whom? What difference does it make to their action? How is it different or the same as what is learned in schools? In what specific ways is what they learn and how they learn antagonistic to and complementary to science in the schools?

It is also clear that much greater emphasis needs to be placed on the technological efficacy of folk culture. This can be done by recognizing the cultural and contextual legitimacy of folk theory and folk wisdom as an alternative to science. Such recognition can occur without compromising the special character of science as a rigorous epistemological form with unique power when applied with humility and care. Such a recognition, however, requires accepting science also as a cultural form. Such acceptance might begin to break down artificial cultural barriers to the application of knowledge to particular problems.

It is worth noting that educators have been slow to accomplish change in these directions in comparison to our colleagues in health. The world wide Primary Health Care initiative of the World Health Organization places great emphasis on recognizing the value of traditional health care systems and working to improve and strengthen existing practices with the appropriate use of scientific methods, rather than to dismantle and to attempt to supplant the wealth of folk wisdom.

Is it possible, for example, for educators to learn from our colleagues in health how to reemphasize the value of existing patterns of learning and teaching about local technologies to be able to build on them rather to supplant them? In Africa, for example, problems of deforestation and declining food production should naturally lead in schools to a study of the analysis of both the traditional farming heritage and existing scientific agricultural knowledge. In such a way we could exercise care that the vital knowledge of folklore not be lost to the formal presentation of biology, chemistry, and physics, general science or even elementary science. We could also exercise care as well that the inappropriate knowledge of folklore continues to contribute to problems of poverty and disease.

## Conclusion

Recognition of the necessity of making education culturally appropriate and occupationally relevant is not new. The Phelps-Stokes report of the 1920's and the early educational policies of the Achimota School in Ghana all show considerable sensitivity and insight into the problem of transforming colonial schools into one appropriate to African settings. Recent regional and national development plans emphasize continuing efforts at developing local relevency in schools.

The discussion in this paper implies that more than cultural appropriateness, in the sense of using local examples, language, and technologies in science education, is necessary. Even within a given culture, for example, in US schools in rather affluent settings, many children learn science as a cultural form appropriate to the school setting without learning how to transfer the science knowledge to the broader cultural context. Science taught with this outcome cannot contribute to national development.

In this sense the argument presented here takes us beyond issues of simply transforming colonial education. It takes us into issues of the specific contribution of science education to the economic development process in all countries. To my knowledge there is no empirical evidence to show how and in what ways science education does in fact contribute. Materials presented as evidence are often anecdotal in character or assertions of "common sense". In order to fully understand the contribution of science education to the development process we need to first begin to look outside of schools at learning and the use of knowledge in the real world - the world of real culture, real production, and real politics.

A project of this kind has begun in Ghana where preliminary drafts of secondary school science materials based on the analysis of traditional technologies and crafts have been produced and tested (Yakubu, 1984). The Foxfire books of the United States are the result of a project in which students documented and studied Appalachian folk heritage. I know of few system-wide attempts to incorporate these materials into curricula. The Third World Science (1982) materials being developed by Iolo Williams and others in Wales may serve as examples for other countries, as might the Association for Science Education Science in Society Materials (1981), also from the UK.

I happen to believe (there is insufficient evidence to know) that it is important for people to know about science. For some people, but certainly not all people, science learned in schools makes a difference in their lives. We know very little, except in anectodal terms, what the difference is or how it is expressed. In not knowing the difference, we can not know the most effective mode of investment in school science to bring about the changes we see as development. It is imperative to get beyond occupational rhetoric and anectdotal evidence. Given the stakes in human lives and the potential for misinvestment of scarce resources, there is much to learn and to learn quickly.

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## Notes

1. Clearly formal science education as part of a larger program of reform played a major role in the transformation of the schools of Japan in the 19th century and the Soviet Union in the 20th.

2. I am grateful to Patri Pugliese of Boston University for pointing this out to me. The lightening rod grew directly out of Benjamin Franklin's theoretical constructs.

3. Laminar flow is the tendency of fluids to flow in layers of differing velocities when they flow by stationary surfaces. The layer in contact with the stationary surface is also stationary. The next layer out has a small velocity, the next layer out a slightly greater velocity, etc.

4. In retrospect, it was fortunate for American not to have had a World Bank or Unesco to insist on the use of the best European experts in the development of its water power development.

5. Knowledge systems here are taken to include a data base of facts and ideas as well as an information processing system to obtain new information and incorporate the information into the data base as knowledge or not.

6. The efforts of one anthropologist to do this is described most vividly in two works by Laura Bohannon. One is her authobiographical novel Return to Laughter (1964) (under the nom de plume of Eleanor Smith Bowen) the other is a short and entertaining piece "Shakespeare in the Bush" (1966) published in the Museum of Natural History Anniversary book Ants, Indians, and Little Dinosaurs (1975).