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This is based on experience and contacts with numerous science educators who have been concerned with "HAVE NOT" (less advantaged/disadvantaged/socially, culturally, and economically different) students around the world. I conclude that recent curricular efforts in science and technology education offer no solutions for these students.

The failure is partly due to the structure of the present system of science and technology education—a structure which is based on the assumption that individuals in various subcultures will respond to the opportunity to receive science and technology education, and that individuals will understand its value to themselves, their families, and their communities. If students do not demonstrate this level of understanding, they are regarded as dumb—that they do not want to or are unable to cope with modern society.

Manipulation of the physical world is the strength that the material culture has to offer and we say, "If only we could teach these 'have-not' students to think logically, that is, scientifically, to bring them into the 20th century and get them to abandon their obviously unsuccessful customs, they would be better equipped to handle the problems and live more productive lives." There is enough truth in this thinking to validate demands for more technological education; but there is also enough narrowness and over-simplification to trap the unwary into believing that technology is a complete system of thought and, therefore, the key to heaven's gate.

If we identify a weakness of various ethnic cultures as their resistance to scientific thinking, then an equal stubbornness on the part of Western-scientific culture exists in its over-commitment to technology.

The historical record of all great civilizations tells us that cultural idealism and technology exist side by side. Great engineering masterpieces in all ethnic cultures testify that science and technology are many thousands of years old. What Westerners call the "industrial revolution" only means an unprecedented acceleration and exceedingly strong emphasis on the technological aspect of human activity. The fact is that five or six thousand years ago, the rise of the great civilizations was not brought about by technology alone, but by radically new social inventions. Keep in mind that the overwhelming commitment to industrial affluence in the West appears to be at the

expense of health and mental balance, and with the advent of the nuclear bomb, survival itself.

Today, less advantaged students are aware of the phenomenal advancements of Europe and post-European cultures. At the same time, they perceive that their own culture has contributed little to the current syndrome of technology. They feel it is too late for them to make a significant contribution to the society in which they must live. Nowhere is ruthless effacement of a people's pride in their own achievements more evident than in current education practice as it affects less advantaged pupils. These students may be of people whose culture was solidly science-based long before modern technology came into existence, yet this fact is ignored in the present teaching curriculum. Have their achievements in applied science, agriculture, construction, and mathematical manipulations been so useless as to be given no consideration in the present science and technology education curriculum? I am not consciously digressing from my purpose here, but only seek to suggest new directions for imparting meaningful science and technology education of our less advantaged (have-not) students.

Now the following question arises:

What, then, should be the nature of science and technology education for these students?

In my opinion, a totally new system of science and technology education is needed that will enable these "have-not" students to develop skills and acquire knowledge, which has a higher probability of producing a better understanding of their environment, and which will make possible for the students an acquaintance with the process or discovery of knowledge. Such a curriculum in science and technology education would lay emphasis on the practical understanding of science and not on theoretical and scientific principles that are unrelated to the students' daily lives. Rather, the emphasis would be placed on the application of scientific knowledge to improve living conditions and to other aspects of everyday life.

Furthermore, science and technology education must be correlated with scientific and technological achievements of the cultural heritage of these less advantaged people. Hopefully, these students may develop pride in their scientifically and technologically rich heritage, develop an interest in learning and understanding of science and technology education,

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and, consequently, achieve satisfaction from success.

To understand adequately the role of science and technology education in the tribal areas, urban slums, Native Indian reserves, American ghettos, or Mohri Natives in New Zealand, it is necessary to ask the following question:

What are the major problems of our "have not" people that science and technology education should prepare the students to tackle intelligently and purposefully?

In the first place, whether it is a ghetto, a reserve, or urban slum where the majority of less advantaged students live and assuming minimal socially healthy conditions, all should work. And this work is practical. In these places there are many problems such as sanitation, health, hygiene, and water pollution, and basic life facilities are very few. The economic condition of these people is really pathetic. Such a situation calls for a science and technology education program to be closely related to the real problems of community life. It must be so presented that the conventional gap between science and technological knowledge and life situation disappears. If such a curriculum could be developed, schools may be transformed into miniature communities where students learn by applying knowledge. Such a curriculum effort may also bring theoretical scientific and technological knowledge out of its isolation and connect it with all the worthy aspects of community life. It calls for schools to utilize students' outside experiences and basing and integrating studies upon the knowledge and information and interests students bring to school. The school thus becomes the center of community life.

With these factors in mind, the author has piloted a teaching and evaluation approach that appears to have promise for success with these students. It is a science and technology teaching program based on environment and is aimed at raising the level of knowledge, skills, and attitudes of these students to allow them to be more productive in their home environments. To achieve this, science and technology education are taught on four levels: the facts level, the concepts level, the values level, and work experience (technology) level. The author taught a course based on this concept to Native Americans in Canada.

In conjunction with the course taught at the different levels, I utilized a personally developed evaluation system. This system took into consideration the unique learning and cultural needs of the students. It provided opportunities for student-teacher interaction. To a large extent, it provided for contract learning

based upon pre-testing to determine the students' knowledge and skills; and it provided mastery learning opportunities (i.e., the students had several opportunities to demonstrate improvement in meeting course criterion measures without penalty).

Very encouraging results were achieved from implementing the evaluation system with the culturally different children in Canada. The students' increased progress and interest in the subject were quite evident.

In my opinion, there is a striking resemblance between culturally different children in Canada (in this case, American indigenous Indians) and "have not" students around the world. These students are generally disinterested in science, and this lack of interest is often a major factor in failure in the subject. It is obvious, also, that these students need individual recognition and attention.

As we internationalize science and technology education, the special needs of the "have nots" of the world must be addressed or we will fail to reach a significant portion of the world's inhabitants. I have attempted to outline in general terms the nature and needs of this group. I have also tried a promising instructional approach with "have nots." I hope that all curriculum developers and instructors will consider the general guideposts I have discussed.

Students attained more when the author's evaluation system was used than with the traditional system. That they learned more is suggested by an increase in average test grades when viewed as a single criterion. There was a general increase in each class. Admittedly, the study is not experimentally "clean," and one certainly cannot infer any causative relationship. Still, subjective observation suggests that some of the components built into the proposed evaluation scheme of Schematic I are tied to a positive shift in interest in the course. The writer believes that the proposed scheme builds on a feeling of reduced failure potential by the students, resulting in a reduced antipathy toward science. In the absence of a thoroughly controlled experiment, this is a tempting explanation of increased achievement.

These results are, of course, highly subjective in interpretation, but the writer's strong feeling is that two very important factors are operating. First, the system makes it clear to the students that their grades are not entirely the result of their rote-learning performance as reflected in test grades. Second, the cycle of teaching and testing activities described reduces the feeling of finality and hopelessness attached to any given evaluation.

The success of these evaluation procedures in stimulating “have-not” students to improve performances has significance for the meaningful science and technology education for these students because of being different by virtue of a vastly different environment and lifestyle from that of the other major population groups.

No matter what is put in print to ensure that a given science and technology education program will be executed in such a way as to de-emphasize memorization and emphasize understanding in the context of real problems, if science educators do not sympathize with this approach or understand it, the outcome

may not be positive. The most important contribution of science educators must always be their ability to make interpretations, make innovations, invent their own study units, and make them close by adapting to opportunities in their classroom and living environment. They must be inventive in demonstrating examples for an idea from the resources at hand in specific situations.

Let us think, organize, and strive together as professionals so that our “have-not” (less advantaged) students can discover for themselves the value of logical inquiry, tested intuition, and the general process of innovation for themselves and their community.

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Skills in Education: A Philosopher’s View

Skill and knowledge intertwine. The choice between them for education is traditionally based on concern for social stability plus the view that knowledge is superior to skill. This must change to let education accord with the need to replace knowledge with the skill of literacy and stability with the skill of democratic control.

Skills Versus Knowledge

Learning and knowledge belong to different subjects—philosophy, psychology, education, and sociology. These differ greatly from each other. In philosophy the theory of knowledge (epistemology) and of method (methodology) concern foundations—what can be known and how? This is of no relevance to education, or to psychology, or least of all to sociology. In psychology the concern is with individual ability and performance; in education it is their acquisition; in sociology it is their institutions.

Some philosophers shift their concern from knowledge to recognized skill and proficiency. Interest in this stems from concern with the problem of knowledge: knowledge claims are more questionable than skill claims. Obviously, knowledge involves skills. Even literacy is generally considered a skill rather than a knowledge, and it is vital for the acquisition of knowledge. Obviously, skill involves knowledge, it is goal-directed, and its application assumes some knowledge of ends and means.

The paradigm is language: its acquisition is the mastery of a skill plus the possession of some knowledge.

This suggests to view knowledge as a skill, the skill of answering correctly some questions. It is a reduction of all knowledge to skill. It is an error: mathematics is rightly viewed by mathematicians as knowledge and by engineers as a skill.

Despite the popularity of the view of knowledge as skill, the study of skill is still neglected. Psychological and educational studies describe specific skills and techniques of their transmission and acquisition. General studies on knowledge and learning abound, but studies on skills in general are scarce. The reason seems obvious: skills as such are mere facilities. There can be specific knowledge about them, about mastery over them, and about their acquisition. More cannot and need not be said. So philosophers suppose that there is nothing to say about skills in general; to acquire and cultivate and exercise them is specific. This is irrationalism. Do not think, do! Act! Live!

This version of irrationalism is Hegel’s. It was endorsed not only by his followers. Gilbert Ryle is known for his distinction between knowing that and knowing how. Michael Polanyi spoke of skills as of personal knowledge or as tacit knowledge, to stress that the skilled are able to transmit their skills in workshops but not to explain how. Polanyi is im-



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portant, and his influence is tremendous, since he has influenced Thomas S. Kuhn, whose term “paradigm” is synonymous with Polanyi’s “personal knowledge” or “tacit knowledge,” which is not knowledge in the sense of the ability to articulate but a skill that cannot be characterized.

According to Polanyi, the practice of the acquisition and transmission of a skill profoundly differs from theorizing about it. A theory may be false, but a practice is a fact. This is his reply to the skeptic critique of rationality. Hence, theory is secondary to practice. It is partial and therefore defective. But practice is a part of reality. Practice precedes theory and may be used to validate it—never the other way around.

Objection: A new practice is often suggested by a theory. Polanyi said, no, the personal knowledge of experts decides how seriously a theory should be taken. Patent testing, too, he said, rests on the tester’s personal knowledge.

This is irrationalism: Eating precedes knowledge of nutrition; therefore, faith precedes knowledge. (Polanyi was religious.) Obviously, eating does come first; yet the theory of nutrition does help improve diets. Polanyi questions this. He contends that the choice of a theory as a practical guide is itself a practice decided by skillful decision makers.

Here is a basic impasse: Knowledge and skills always go hand in hand; it is hard to decide which of the two is the basis for the other. Viewed critically, they are corrective of each other and they can help improve each other. This cooperation is masked by the prejudices that beset learning due to the institution view of a division of labor between the inferior skilled and the venerable learned.

Knowledge and Skills as Adjustments

The scientific revolution was heralded by Sir Francis Bacon. His approval of technology is a major component of the ethos of the Age of Reason that fathered the industrial revolution. He was no pragmatist; he valued theory both intellectually and practically. The basis of the classical theory of learning of the Age of Reason is the idea of Bacon’s in the modification of John Locke: All learning is one—babes-in-arms, infants and adults, common people, travelers and researchers, Christians, Jews and pagans, they all use the same method, the inductive method of learning from experience by association.

Learning is thus polarized to the acquisition of the extant knowledge and of the new. Their mixture in infancy and in research refutes this; it holds only for instruction, since pupils’

innovations are proscribed. We adjust by imitation and invention jointly. How we adjust is unexplored. Success of efforts to adjust is not assured. Adjustments are hard to compare, except longitudinally. We are trained to be inflexible, on the presumption that it contributes to social stability.

Stability was universally admired. In the Age of Reason, this was tacitly taken as self-understood. The first to speak against stability was Karl Popper, who suggested in 1945 that it should be replaced by democratic control. This is no longer a live issue; stability in the modern world is unrealizable. (Those who speak in its favor confuse the desire for it with the wish for some regularity and for the reliability of expectations for peace and for high quality of life.)

The change from the demand for stability to one for some regularity permits adults to remain as flexible as children. Can adaptability be kept and developed past puberty? Classical rationalists answered it positively. The only obstacle to it, they said, is the prejudices acquired by instruction. This led visionaries to oppose schooling. They were in error. Schooling is a necessary evil though instruction can be eliminated almost totally; being replaced by training. Training to be critically minded is basic, since it reduces prejudice. Schools should offer training in learning.

Adjustment is complex and difficult. The adjusting child learns to behave like others. This leads to disaster. The child then learns to discriminate: adults and children differ, as do male and female, relatives and strangers, rich and poor, the strong and the weak. Discrimination is hard to learn. What makes people different? Without a good answer, discrimination is learned as adjustment: one must adjust. One of the most reactionary social thinkers ever, Erik Erikson, viewed those whose skill at social discrimination is impaired as mentally incompetent. Yet in traditional societies his theory obtains and is endorsed. Normal conduct includes skills regarding social discrimination, and these is impossible without familiarity with established rules and compliance with them. Only a century ago in the civilized world defiant women were certified as mad.

A child moving to new surroundings meets the demand for the acquisition of new knowledge and skills. There is no basic difference between adjusting the second time and the first. There is no basic difference between the acquisition of a second language and a first, except that social pressure may put the bilingual at a disadvantage, and then it may serve the bigot researcher to support irredentism despite all evidence to the contrary. As long as

one freely encounters two or more languages at an early age, one meets with no problem. But there is a problem in moving as adults to new surroundings. The reaction to this experience is mixed; it is often disgust combined with fascination, rooted in the demand for a barrier between us and them, erected in the name of social stability.

The barrier between us and them is justified by some theory that depicts us as superior, contrary to the doctrine that was called “the brotherhood of men” and that is better referred to as the siblinghood of humanity. The ancient Greeks realized that we are to them as they are to us—more or less. This led to the distinction between truth by nature, which is demonstrable, and truth by convention, which is arbitrary. The doctrine of the siblinghood of humanity is true by nature and is thus superior to the doctrine of superiority, since only truth by nature binds. This was identified as demonstrable truths. Somehow, no one ever asked: How is the doctrine of the siblinghood of humanity demonstrated? Since it was (rightly) taken for granted that all doctrines of superiority are truths by convention, the doctrine of the siblinghood of humanity was (wrongly) never questioned.

And so, the very idea that knowledge is not confined to national boundaries was taken as identical with the idea that the siblinghood of humanity is of truth by nature: hence, the distinction between German and British philosophy is bogus.

The Doctrine of Prejudice

Knowledge is universal. This is explained as due to a similarity of all intellects: “all men are created equal” (intellectually, not physically). Few examples of universally endorsed practices were known, but quite a few natural truths were. So, of theory and practice, not surprisingly the former was deemed basic. When art is viewed as employing a universal language, it was meant as praise. When skills and techniques are recognized as universal, such as scientific technology and the skills associated with it, they are praised above other skills.

In the Age of Reason, science was expected to bring peace and prosperity to the world; enlightenment was then deemed highly valuable both intellectually and practically. But this great progress can be attained only at a cost: one must give up whatever opinion one has; all bias must be renounced. This is Bacon’s doctrine of prejudice. He suggested that research will not reveal the truth as long as researchers adhere to preconceived notions. Conjectures are evil, he said, since they color

perceptions and distort images of reality.

This idea is nowadays regrettably often overlooked, though ideas inherited from the Age of Reason make no sense without it. The preoccupation these days with rational degrees of belief is rooted in the conviction that entertaining a belief not based on facts is dangerous. Also, Bacon’s doctrine is at the root of Marx’s view of class-prejudice, of Freud’s view of neuroses as prejudices hard to eradicate, and of Wittgenstein’s view that clarity is important and is risked by the ambiguity of language. By this idea people refuse to admit error; error is then eliminated only through the demise of its perpetrator. It is repeatedly rediscovered by psychologists. Recently it was ascribed to Gordon Allport and to Leon Festinger.

The doctrine of prejudice was refuted by William Whewell early in the 19th century, as the result of the overthrow of Newton’s theory of light (1818). Were it true, then it would never have been given up, since earlier it was unanimously endorsed. Popper went further. He said that one can never be free of all prejudice; those who deem themselves free of prejudice are the greatest offenders, since they find no need to be critical of views they consider true, and so they are prejudiced to the utmost.

Bacon contrasted instruction and study. The one is the transmission of prejudice that blocks the road to study that is learning fresh from the hand of nature. Hence, children are born researchers. In the 20th century, this led to the discovery method in education. Remarkably, this excessively simple-minded idea was taken seriously enough to be repeatedly implemented. It is monumental evidence to the strength of the hold of Bacon’s doctrine of prejudice on modern science curriculum planners. The contrary opinion is also popular: national prejudices should be taught, since they contribute to social stability. It should be generally agreed that neither the total adherence to tradition nor its total rejection is a viable option. Rethinking the aim of education and the reform of the educational system is imperative.

Training to Replace Teaching

Rationalists always took this for granted: Education is most significant, and teaching is a poor substitute for learning. Why teach then? Rousseau said that since children are autonomous, we should not teach. Kant said that the aim of education is to train for autonomy. But schools suppress it. What is the best way to promote it? The advocates of the democratic school system or the open school system sug-

gest that democratic schools are the best tools for the education for autonomy.

If education is training, then training for autonomy should include training for skills for the enhancement of autonomy, moral but also economic. The transmission of skills may then replace the traditional transmission of knowledge. The following questions may then be raised: How much knowledge is needed for effective training? What skills are essential for what other skills? How can education be viewed as vocational training? The availability of pocket calculators renders detailed training in arithmetic unnecessary, unless experience shows that mathematical training requires it. Some familiarity with the national ethos is essential for the reasonably competent citizen (though with no need for indoctrination). The ability to make a simple instrument is essential for becoming a physicist just because simple laboratory operations are executed with the aid of high-tech instruments and computer programs.

The split of schools to vocational and scholarly should vanish, as well as their isolation. Educational bureaucracy and its elitism are

growing. Combining learning with industry is becoming very attractive, especially in Sweden, where job improvement, job rotation, and semi-autonomous teams are increasingly common, showing how to close the gap between the academy and industry. Study, work, and play are different activities, yet their separation is unnecessary and harmful.

Reform should transform teachers into coaches. This will remove indoctrination. The end of training in general and of every specific program should be stated and debated. The reduction of indoctrination will invite the inquiry into the possibility of prolonging adaptability quite generally. Perhaps this is just a dream, but it is too exciting not to examine it empirically.

Overcoming discrimination will eliminate barriers to adjustment. The supreme source of discrimination is schooling. This will change as schooling ceases to instruct knowledge and instead train for skills. Scholarly skills and diverse daily skills and artistic skills will be then integrated. This will go very well together with pluralist participatory democracy.

“It’s Pretty Scary”: The Traumas of Change

Paul Black

Innovation in education is a stressful and often painful process for all involved, and particularly for teachers. The quote in my title came from a teacher involved in one of 23 innovations studied in detail in a recent Organization for Economic Co-operation and Development (OECD) study of the processes of change in science, mathematics, and technology education across 13 of its member countries. I believe that a general distillation of lessons drawn from the results (Black & Atkin, 1996) contains many lessons of importance for school technology.

It is clear that, for countries all over the world, technology is “the new kid on the block” in the school curriculum. This new kid is exciting, but difficult. The JISTEC 1996 underlined this view: the numbers, over 800 delegates from 80 countries, were evidence of growth in interest, while the diversity of the presentations, and of the conceptions of school technology underlying them, was evidence of the excitement and of the difficulties. Given that, in many countries, school technology is either new or recently re-born, it follows that its future in schools depends upon the implementation of innovation and change, and so we have to look hard at the prospects for

success of innovative change. Here the omens are not encouraging: the pantheon of curriculum revolutions is crowded with the gods who failed.

One motivation for international study is that countries naturally look at the ideas and practices in other countries to see whether they can improve their own systems. There are many dangers in attempting such transfer, and the OECD work signaled the need for a more complex understanding of innovations, one which tries to understand how their growth depends on the environment of their country’s particular culture. However, six common themes emerged across the OECD cases as key issues. I shall discuss these in turn before drawing some general conclusions.

THE IMPETUS FOR CHANGE

Some countries are driven by “demons”—standards are falling, other countries stand higher in the league tables of the Third International Mathematics and Science Study (TIMSS), international competitiveness is threatened. Some press for students to be better prepared for work in employment, with well-developed general skills so that they can be flexible, learning for today’s task but well able to learn afresh as technology transforms tomorrow’s task.

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A different impulse springs from the need for future citizens to take effective control of changes in their societies, capable of critical and well-informed judgment, and with a well-developed awareness of values involved in any social change. A statement from the USA science education reform project, Project 2061, underscores the point as follows:

The terms and circumstances of human existence can be expected to change radically during the next human life span. Science, mathematics and technology will be at the center of that change—causing it, shaping it, responding to it. [Scientific literacy] is essential to the education of today's children for tomorrow's world. (Black & Atkin, 1996, p. 15)

Changing Subjects

The studies show that the nature of school subjects is changing in profound ways in many countries. For example, in science there are notable shifts, one from presenting science as disembodied truth to describing it as the product of real people, the other from emphasis on pure research to stress on complex fields of application. The latter leads to a focus on interdisciplinary problems and so naturally promotes a trend towards teaching all the sciences as a single unified subject or as a closely coordinated set. This emphasis on the practical can also lead naturally to discussion of the wider effects of practical applications, and some teachers use these opportunities to introduce discussion of issues of social choice and moral values into science classrooms, although many other science teachers do not feel comfortable handling such discussions. There is also a rather different emphasis on rethinking the presentation of science to students through their own experience of practical investigations so that they can experience its work in a more authentic way.

These trends, taken together, amount to a re-conceptualization of school science in which the definition of the subject is no longer determined by the priorities of research scientists but is fashioned by a broader educational agenda in the control of teachers and, to a degree, the wider public. Such re-definition of the subjects is bound to have an impact on the role of technology education and on its relationship to science and mathematics education. The new approaches would seem to support a broad approach to school technology giving high priority to the need for better informed citizens and lower priority to the needs to train future engineers or craft experts.

Teaching and Learning

Changes across many countries are being

driven by changed ideas about the ways in which students can learn most effectively. The traditional “delivery” model of learning was underpinned by a set of assumptions about learning, notably that:

- “knowing that” must come before “knowing how”;
- the effective sequence of learning is first to receive and memorize, then to practice routine exercises, and only then attempt to apply;
- it is better to teach at the abstract level first and to leave the business of application in many different contexts to a later stage;
- motivation is to be achieved by external pressure on the learner, not by change in the mode of learning or the presentation of the subject; and
- difficulty or failure in learning arises from an innate lack of ability, or inadequate effort, rather than from any mismatch between the teaching and the needs of students.

These assumptions are no longer accepted. The emphasis now is on constructivist approaches, which imply that students must clarify and express their own beliefs and then be challenged to change them so that learning becomes a process of individual active construction of meanings.

In this scenario, it is clear that technology can play an important role if it is defined as the subject in which real problems are tackled in their own terms, the need for a solution being pursued by calling on whatever resources of materials, knowledge, and skills appear necessary, irrespective of which school subjects own or can supply these resources. In these terms, it can become the most radically cross-curricular of “subjects.”

Assessment

It was notable that as the case studies developed, it seemed as if many of those pursuing innovations did not want to incorporate ideas or initiatives about assessment in their work. This may have been because it was seen as a threatening or, at least, problematic area. Assessment commonly has a negative image because summative assessment with its high stakes, both for grades, or certificates, or university entry, and in school accountability, dominates teaching and, sadly, also narrows its scope by the use of cheap measures of performance.

However, there were some bright spots. Studies in Norway and Spain developed self-assessment by pupils, which improved their sense of control and responsibility for their learning. In France, new national tests provided diagnostic information of value to teach-

ers. These moves were emphasizing two developments. One is that the role of pupils in their own assessment is essential if they are to take fuller responsibility for their learning overall. The other is that teachers' skills in day-to-day classroom assessment need to be improved, both to enhance learning and so that eventually teachers can be trusted to take an enhanced role in high-stakes assessment. For technology, where short external testing cannot reflect the aim of developing practical capability, such developments will be essential.

Teachers in Change

Change is often deeply disturbing for teachers. It can require that they take risks in establishing new ways of relating to their students, it can threaten the teacher's authority and pedagogic expertise in the classroom because it demands new ways of working with learners, and it often requires a level of subject competence that teachers do not have.

If teachers are to cope successfully with change, several conditions seem to be important. These are briefly set out as follows:

- **Dis-equilibrium:** Teachers must themselves share a dissatisfaction with present programs and see the need for improvement in their work.
- **Exposure to alternatives:** Teachers need to be convinced that there are better approaches.
- **Existence proof:** The feasibility of the implementation of any proposed changes, in classrooms like their own, has to be demonstrated.
- **Modeling:** Teachers should be in touch with peers who are operating the innovation, who can serve as models for them when they prepare to put the innovation into practice in their own classrooms.
- **Support:** Teachers have to be given support, within their own district and particularly in their own school—a support that recognizes that innovation cannot be risk free and that will allow for, and help them to cope with, early problems and even failures.
- **Experimentation:** Opportunities to try out new ideas and methods with groups of students from outside their own schools can be particularly useful.
- **Reflection:** It is hard to assess or understand what is happening in a busy classroom while one is on one's feet trying to manage the situation—opportunities to sit back and reflect, alone and with colleagues, are essential if lessons are to be learned from one's first struggles with an innovative approach.

- **A role:** Teachers have to be treated as partners in the formulation as well as in the implementation of reforms, and they have to be given flexibility to adapt as they learn how to implement broadly specified targets.

The Student's Perspective

It became clear during the studies that students could offer very useful insights on the processes of reform and that change could often be stressful and disorienting for them. Changes in the definition of the subjects meant that the image of the subject that they were acquiring from the school's presentation had to be changed, sometimes in a radical way. At the same time, their experience of learning might also have to change so that they would have to become accustomed to new ideas about what constitutes learning—and therefore learn to behave differently in their classrooms.

A teacher in Spain described the experience of working with such difficulties with students as follows:

Children receive so much information, and at such an incredible rate that they are unable to assimilate it, and this is precisely what is happening with their learning. [As in formulating] hypotheses, the conclusions and analysis section that come at the end of each activity proves to be very difficult with students. This is because they simply swallow everything. . . . They are just like the television news. They give information but they don't analyze it. (Black & Atkin, 1996, p. 151)

This extract illustrates a feature that was common across several reform programs—that students needed particular help in assuming greater independence in their learning. Such independence meant that they had to break the habits of passivity and of dependence on their teachers.

STRATEGIES FOR CHANGE

Several common features emerge fairly clearly from this summary as follows:

- The distinction between "top-down" and "bottom-up" reforms describes two ends of a spectrum rather than a dichotomy. Neither approach, on its own, will guarantee success or lead to certain failure.
- Reforms cannot work if they are too radical. Procedures and targets that are completely foreign to teachers will be seen as threats, and they may easily become demoralized and resistant. It is important rather to build on existing strengths.
- It takes teachers and schools considerable time to adapt to reforms, and it is both unrealistic and unhelpful to expect

changes to succeed at the first attempt. The lessons that teachers learn in practice should be fed back in a process of evolution of a reform.

- Each reform should be considered in relation to the particular context of culture and tradition in which it is made concrete, and any reform should be regarded as an organic whole. The machine metaphor characteristic of the age of “the enlightenment” does not apply. Likewise, the six themes discussed are intertwined within any actual innovation.
- The complex interactions implied by the previous point are an enduring feature. Any change that works with one aspect only of an educational system will inevitably affect, and be affected by, other aspects, so planning must be systemic.

A systemic approach does not imply that any reform has to aim to change every possible aspect of a system—change would be hardly possible if this were true. The lesson is rather that any plan first has to formulate a broad picture of the educational system. Then, in the light of this picture, a boundary has to be established for the proposed innovation. All those elements inside the boundary should be tackled in a coherent and mutually supportive way while all those elements outside the boundary will be accepted as they are, so that the innovation will have to adapt and accommodate to any influences that they may exert. A suitable metaphor might be that of defining an ecological niche in which the reform plant may flourish. It follows that even a flourishing plant may not survive if it is transplanted into a different ecological system, or if the ecology is altered by changes outside the boundary.

Another aspect of a systemic approach is that a wide range of persons and agencies should be involved in educational innovation—with the corollary that they share responsibility for promoting and supporting it.

Thus, parents, community groups, those working in media, museums and zoos, administrators, businesses, researchers, teacher educators, and publishers may all have a part to play.

Even if the advent of technology as a new subject were not a prominent feature of the scene, the picture that the studies paint of science and mathematics education being redefined and reorganized as schools try to respond—to changes in society and to new ideas about learning—is not one that is likely to settle down to equilibrium. It seems, rather, that as the pace of technologically driven social change is likely to be maintained, schools may be faced with demands on them that change more rapidly than they are able to respond, which is to say that education may never catch up. Given this prospect, and accepting the argument that the teacher stands at a focal point in the implementation of any change, it seems inevitable that educational systems will have to reconsider the role and work of teachers quite radically. For example, if teachers were to be given far more time free from classroom duties so that they could interact more closely with the world outside the school and plan their work accordingly, schools might be better placed to respond to change and to look more realistically to the needs of their students as they enter adult society.

If such considerations are important in the established areas of science and mathematics, they will apply with even more force to technology as a new or reborn school subject. While there cannot be any single recipe even for defining, let alone implementing, school technology as a new subject, it is clear that a modestly slow approach will be essential. Those anxious to promote this important development in the school curriculum should temper their enthusiasm and impatience with the realization that it is possible to build on modest success, but very hard to recover from ambitious failure.

Reference

Black, P. J., & Atkin, J. M. (Eds.). 1996. *Changing the subject: Innovations in science, mathematics and technology education*. Routledge: London.

Details of the case studies, with information about where to obtain the full reports, may be found in Black & Atkin (1996).

