

# **Innovation and Change in Science Education**

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## **Abstract**

Over the past few years, 13 member countries of the Organisation for Economic Co-operation and Development (OECD) have between them undertaken case studies of 23 different innovations each aimed at reform of school education in science, mathematics or technology. The findings of these studies have formed the basis of a book about innovation and change in these subjects. The paper uses a review of these findings to present a general argument about the way in which reforms in education ought to be planned. It is clear that radical changes in teaching and learning cannot be achieved by external imposition, and that successful implementation of such changes can take several years. The reforms in science are characterised by new ideas which challenge the fight of subject experts to have the main say in defining the roles of these subjects in education. They also show a common move towards replacing the teaching of separate sciences by teaching in science regarded as a single subject. There is also a shift towards a science curriculum focused on issues of direct relevance and interest to students and future citizens rather than on conceptual structures. These trends, taken together, constitute a significant challenge to the place of physics education in the school curriculum of the future. At the same time, the establishment of technology, as a new subject, or as a subject re-born, both raises further questions about the boundary of science education and illustrates the difficulties of making radical changes in a school subject.

## **Introduction**

The evidence and ideas discussed in this paper arise from a project of the Organisation for Economic Co-operation and Development (OECD). This project aimed to study innovation and change in Science Mathematics and Technology Education (SMTE). In its first phase, representatives from member countries studied examples of particular innovations in one another's countries. This work showed that although the comparisons raised a number of important questions, it was not possible to achieve useful understanding without a far more detailed knowledge of each innovation. So, in a second phase, countries were invited to set up and support detailed case studies of innovations which they would each select for their importance in their own country. In response, thirteen countries volunteered, offering in total 23 case studies. On the basis

of these, a book distilling the issues from all 23 studies has been published (Black and Atkin 1996). The individual studies will be published separately in their own countries and information about them will be available from the OECD in Paris. Eight of the case studies are from the USA, and these will also be published in a more detailed form in the USA with extensive discussion of the issues that they underline (Raizen and Britton 1996). I should acknowledge that support from the US Department of Education and the US National Science Foundation has been of particular value in making it possible for OECD to co-ordinate, and distill from, the results of the work supported by each of the contributing countries.

Although my comments are based on the project's report, this paper sets forth my own priorities and opinions and does not commit the OECD or the agencies which have supported the work.

The countries contributing, being members of the OECD, do not include any from Africa, South or Central America, whilst Japan is the only Asian country involved. Thus the developing world countries are not represented, although I believe that many of the lessons would be applicable to all countries.

Likewise, since the work had to be based on the innovations that the countries themselves chose to study, the subject distribution was not ideally balanced. However, ten were concerned exclusively with science education, seven exclusively with mathematics, and a further three with science and mathematics combined. Technology education was not well represented - only two of the studies, from the Netherlands and from Scotland - looked at separate courses in Technology, and another - from Tasmania - looked at an innovation system in which science, mathematics and technology were all involved. Although it was concerned with two other subjects as well as with science, and with science as a whole rather than any one of the sciences, I believe this study is relevant to the concerns of physics education for three reasons.

The first reason is that, as the studies make clear, the school subject of science is undergoing rapid change in ways that have important implication for each of the main sciences, both as separate subjects and in relationship to one another and to other subjects in the curriculum. At the same time, science is bound to be affected by technology - a school subject which is emerging in many countries as either new or recently re-born.

Where rapid changes are under way, it is important that the conditions for success of innovations be understood as fully as possible. It should be borne in mind that the OECD member countries promoted this project because their own experience is that innovation in education is a difficult and

risky enterprise. Many innovations in the past have achieved only limited success, and some have failed to achieve their main aims. So it seemed important to try to ensure that future policies might have a better prospect of success because they might be based on a better understanding of the processes of change.

The second reason is that countries naturally look at the ideas and practices in other countries to see whether they can improve their own systems. The rich variety of interchanges that this present conference makes available should stimulate interchange, and possibly transfer, of ideas. However, there are many dangers in attempting such transfer, and the issues I shall discuss should help in foreseeing and avoiding such dangers.

The third reason is that innovation in education is a stressful and often painful process for all involved, and particularly for teachers. Policy makers and administrators owe a duty, to themselves and to their schools, to plan as wisely as they can to foresee and minimize the stress and to reduce the pain.

The analysis of the case studies has led to the identification of six main themes, which will form the main sections of this paper. They are as follows : -

- The Impetus for Change
- Changing Subjects
- Teaching and Learning
- Assessment
- Teachers in Change
- The Students' Perspective

These six themes may be regarded as a framework of analysis which the project has used to distill the main lessons from the case studies. They might also be regarded as a reflection on change - a portrait of the landscape composed by the authors. More dangerously, they could be treated as a guide to action, or at least as a check -list. The danger will be discussed in my closing section where I shall attempt to draw some general conclusions about the work.

In adopting this approach, I do not wish to argue that these six are the only issues involved- indeed it will be obvious that there are many others. However, these six have emerged as the most significant when the 23 case studies are reviewed, so it would seem that attention to these should have the first priority in any analysis or in any planning for the future.

Throughout this paper, the discussion of technology is not concerned with information technology and the uses of computers. The term technology as used here refers to a school subject that is concerned with all aspects of the design, construction and evaluation of artifacts, systems and environments to meet human needs. In many countries there is no such subject in schools, in others the subject is more narrowly defined (e.g. as craft only, or as applied science only), in a few it is new and is broadly defined to include, for example, food, fabrics, electronics and control, mechanisms, and ethical and social issues (Layton 1994).

## **The Impetus for Change**

Some countries or groups are impelled by fears - they might believe that standards in their schools are falling. Some leaders may look back on their own educational histories and long for a return to their certainties - expressed perhaps as a move 'back to basics'. Results in international test exercises might show their country low down in an international league table. Stories of successful ventures in other places may make them devalue their work and wish to imitate others.

Whilst many of these discomforts are driven by imagined 'demons', they can have a source in real concerns about international competitiveness and about the related need to ensure a well educated work force. Here there is both the desire for a school students to be more directly prepared for work in employment, and a growing need for a workforce which has well developed general skills so that they can be flexible, learning for today's task but were able to learn afresh as technology transforms tomorrow's task. A very different impulse springs from the need for future citizens to take effective control of the development of their societies. To do this, they must be capable of critical and well informed judgment, and have a well developed awareness of values involved any in social change.

This latter point can expand into a more positive vision of the future which nevertheless present substantial challenges to education. For example, a statement of 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 centre 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.

Such a purpose finds echoes in the policy formulations for the reforms in Spain, Tasmania, and Germany. The Japanese reforms show a still broader philosophy in stating that the aim of the new science course at elementary school level is:

to ensure, keeping the 21st century in view, the development of people with rich hearts who will be capable of coping with changes in our society such as internationalisation in different sectors and the spread of information media.

A different set of purposes which drive or help shape many innovations focus on the securing of enhanced inclusiveness and equity through education. Differences of social class, gender, ethnic origin, family background, home language, and the problematics of differing "ability", motivations and learning styles amongst students can all create obstacles for particular groups of children so that educational organisations must be constantly vigilant to remove such obstacles. The means may be direct, such as using examples from a minority group's culture, in a technology lesson, or indirect, for instance by deferring choice and specialisation until students are sufficiently mature to fully understand the consequences of their choices for their future.

A notable and comparatively recent change in reform plans is expressed in the concept of Systemic Reform. One main message here 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, in addition to national and local governments and their schools, parents, community groups, those working in media, museums and zoos, administrators, businesses, researchers, teacher educators, publishers, and professional and voluntary organisations involving many of these groups, may all have a part to play. Thus the Project 2061 mentioned above had its origin in one outstanding leader working within an association of professional scientists, the American Association for the Advancement of Science. This makes it a national project with high prestige, but it is top-down project needing to inspire schools so that they will work to transform its vision into reality. Conversely, the project for Practicing Integration in Science Education started in one region in Germany through the action of teachers supported by a research institution, and was subsequently promoted first by the local government for its own region and subsequently by the federal government across all regions

Other motivations for change which are positive ambitions rather than reactions to 'demons' are to be found closer to the classroom. For some, new and expanded visions of the ways in which learning might be made more effective and pedagogy transformed are sustaining efforts to change.

For others, the drive is for a change in the social status and roles which teachers and students take on themselves or have thrust upon them, because of a belief that without such change all more external efforts are bound to fail.

## **Changing Subjects**

The studies show that the nature of school subjects is changing in profound ways in many countries. Science is the example studied most thoroughly. The changes in this subject show several different features. One is a shift from presentation of science as disembodied truth to describing it as the products of the work of many real people. Another is to move the emphasis away from pure research towards the more complex fields of application. This is a move towards the practical and the everyday as the contexts in which to learn science. The traditional route - to teach deep concepts and then show how they lead to applications - is being inverted. The applications now come first, so the work is based on topics which are chosen for their interest and relevance to young people - to their daily lives and to their future as citizens. Typical examples are pollution, conservation, global warming, and genetic engineering. The task of curriculum design is then more complex. What has to be achieved is to articulate the way such topics are pursued, so that the studies will lead to acquisition of the profound concepts and stringent methodologies of science. Students need these both to penetrate further into the issues than the TV sound-bites allow, and to acquire an authentic and useful basis for their future interest in science.

The enhanced focus on such problems, which commonly have an interdisciplinary character, naturally links with a trend towards teaching all the sciences as a single unified subject or as a closely co-ordinated set. However, this movement has two important consequences for those committed to physics education. One is that the changes are accompanied by a move away from the teaching of the separate sciences in secondary schools, towards having a single course in which these are taught in a co-ordinated or

This approach has been the dominant one in new curriculum materials by the Nuffield project for technology in the curriculum in England (Barlex et al. 1995)

This same emphasis on the practical is also linked to introduction of issues of social choice and so of moral values into discussions in science classrooms - a shift which many science teachers find uncomfortable. They may be helped here by collaboration with teachers of other subjects, not only

within the sciences but also with mathematics, with technology and with the humanities. Such cross-curricular work is also being developed in the innovations in a few countries because it is seen to be a necessary part of dealing more realistically with human problems.

These changes in science are reflected by equally profound changes in school mathematics. Here the trend is to decrease the emphasis on the teaching of a formal set of rules and procedures and to enhance the tackling of problems. The intention is that students may come to see mathematics as a way of dealing with problems by constructing models of reality and manipulating them. This trend works with effects of the onset of increasingly powerful calculators; when hand-held machines can perform all the common operations of arithmetic and algebra, can differentiate, integrate and solve differential equations, and can draw and help interpret graphs, the need for students to learn how to perform all of these operations by hand must obviously be reconsidered.

It is harder to speak of a trend with only three examples to consider from technology. What these have in common is a commitment to a new, or newly re-defined, school subject. Prominent in the re-definitions are an emphasis on the meeting of human needs by the design and realisation of optimum - not perfect - solutions. These approaches emphasise a broad view of technology which gives 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 memorise, then to use in routine exercises so as to develop familiarity and understanding, before attempting 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;

\* difficulty or failure in learning by the traditional route arises from an innate lack of ability, or inadequate effort, rather than from any mismatch between the teacher's preferred learning style and the student's.

These assumptions have now been challenged, and many have abandoned almost all of them. They are replaced by emphasis on constructivist approaches, which implies that students must clarify and express their own beliefs and be challenged to develop or change these in ways that make it possible for them to give personal meaning to what they are learning. Thus a science teacher involved in the reforms in Spain stated that: -

*I believe we have a whole new conception of how students learn and I feel that this changes everything ... But the true innovation is not to be found in changing methodologies but rather in transforming 'didactic attitudes'. ... if learning is understood as a process of 'individual active construction', then educational activity does not always have to consist of children manipulating things.*

This type of change has profound implications, for it changes the way teaching programmes are planned and the ways in which pedagogy is understood and practised. It also implies that the roles of both teachers and students and the relationships between them have to change.

The difficulties for teachers are illustrated by another quotation from a science teacher in Spain: -

*What we are seeing at present is that the teachers are not taking on the new role that is required of them. They have not been able to break away from their role as mere lecturers whose purpose is the transmission of knowledge.*

The challenge is also experienced by students. The following quotation comes from a report on an innovation in physics teaching in British Columbia: -

*the students involvement in shaping the way they approached the topics resonated with our original intent to develop the unit around contexts familiar to students. Providing choice and flexibility to the students allowed them to do this better than the instructors could. As the unit progressed we saw our intent to allow a variety of approaches by the students blossom into an eclectic mix of methods for gathering, synthesising and presenting information.*

However, there are also problems as new methods and roles can disorient students and give rise to anxieties - a teacher from an innovative mathematics programme in the USA describes this problem as follows : -

*It bothers them that we don't tell them everything. It does, and their anxiety level is definitely increased because these are students that have been very successful in traditional-type programmes. And now they're in an un-traditional program.. It takes them a little while to start getting used to things. And we really see some that start to just go ahead in this as they work more together.*

Across all three subjects, i.e. in technology and mathematics as well as in science , this new approach is producing certain common characteristics. One is the emphasis on hands-on and, where appropriate, practical work. Others are emphasis on real-world problems, on students taking responsibility for the ways that they tackle these and on these efforts being conducted through collaborative work in groups, rather than by individuals who often see themselves as in competition with their peers. Teachers and evaluators report that these changes are enhancing the maturity and confidence of their students. New resources for learning, notably computers and the possibilities opened up by collaboration with local communities and institutions, are being used to support and enrich these trends.

In these scenarios, it is clear that technology, where it is newly defined as a broad school subject, might come to play a unique role in the curriculum, for the new trend is to make it a subject in which 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'. It can also, through such an approach, achieve a more authentic realism than is possible in subject work constrained by the disciplinary agenda of the particular subject. In such a scenario, science becomes one of many subjects which provide ideas and resources for use in technology - an important provider but by no means the sole source.

## **Assessment**

It was notable that, as the case studies developed, it was difficult to see any focus on assessment as an issue in most of them. 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. There are several reasons why this area should have such a negative image.

One is the inevitable tension between the different purposes of assessment. The formative purpose is served by collection of information for immediate use by teachers to improve students progress in learning, which means that it is embedded in classroom activity and must be under control of teachers.

The summative purpose is concerned with providing overall information about students, to guide their transfer between different stages of schooling and their move out of schools to employment or to further education. This purpose is closely related to the demands for accountability of schools and both are often served by the same data. These purposes are often served by use of external tests, with the danger that these can dominate classroom work.

Whatever the purpose, the difficulty is to ensure that assessment data is evoked by student activities which are valid, in that they correspond to the aims of the learning and give results which can be validly interpreted as indicators of that learning. With learning activities being moved towards more complex and open-ended problem work, away from short and algorithmic exercises, these requirements become hard to meet with any short externally set tests.

One of the projects, a Norwegian innovation in mathematics education, took as its priority students' self-assessment and peer assessments. This required the development of a range of new learning activities. Examples were students setting their own problems, reporting their work to peers with short talks or by posters, collecting their best work into portfolios, and marking their own and one another's class tests. The whole activity improved formative assessment by providing a more lively flow of information about progress to the teachers. It also developed the students, as the following quotation from one of the teachers shows:

*In this field many of them have undergone a fine development. They see it can be of use to them and are now honest and clever when assessing themselves. As a result of this they now understand that they must take responsibility for their own learning.*

One consequence of the experiment is that the national body responsible for assessment, which promoted this venture, is now thinking of using student portfolios to replace parts of the general school-leaving examination.

The example is notable in that formative evaluation is poorly developed in many systems (Black 1993). It also shows that, as in the teaching and learning work described above, improvements in assessment require difficult changes in the roles of both teachers and their students.

A different perspective is revealed by the evaluation of a centrally directed initiative in France, where students at three ages in all schools were required to take externally provided tests in mathematics. However, the tests were to be taken at the beginning of a school year and were designed to be used by the teachers who, on starting out with new classes, were not responsible for the results but were expected to use them as diagnostic indicators of the needs of students in these classes. To serve this purpose, the tests were expertly designed to provide diagnostic information in several aspects thought to be important in progression in the learning of mathematics. The tests were generally welcomed by teachers, for whom training in the interpretation of the results was provided. However there were problems. One was that the results seemed only to be useful as short-term indicators of students' proficiency - they did not give reliable predictions for work within even a few weeks of the tests. more seriously, the test results exposed a wide range of differences between pupils, with difficulties which called for programmes of remediation. however, the teachers felt that they had neither the resources or the time to provide the remedial work that was clearly necessary.

In both of these examples, assessment changes were used as the main instrument of innovation. Less common were examples of assessment being used to support innovations

- changes in the California state-wide system were a noteworthy example. In this state's programme of reform of science education, the approach taken was a systemic one i.e. there was a very serious attempt to change all aspects of the education system which might constrain or support the curriculum innovations which were the central aim of the reform. This is a good example of the positive and ambitious approach to assessment that may be essential if innovations are not to be hampered, or even fail, through pressures of uncoordinated assessment procedures.

## **Teachers in change**

It is clear from the arguments above that the current trend in innovations require change in teachers' work in their classrooms. However, they also call for more emphasis on teachers' professional work outside classrooms. Many countries recognise that if new aims and methods are to be translated into effective classroom practice, teachers have to be given flexibility to implement broadly specified targets. Given this, then attempts to implement reforms through changes in initial teacher training are, on their own, too slow in their overall effect on schools as a whole. In-service training is clearly

essential, but this will not work either if it is assumed that for such training there are 'experts' who can tell teachers what to do. It seems generally accepted that for effective innovation, teachers have to act as partners in the formulation as well as in the implementation of reforms, and for such work they need time to collaborate with peers, to plan new pedagogy and to refine the new methods through shared experiences and reflection. This emphasis on teacher responsibility for change was particularly well marked in the systemic reform plans for science of the state of California, in other innovations in mathematics education in the USA, and in new reforms of science education in Germany, Norway and Spain.

However, even where teachers have the stimulus and support which can derive from mutual collaboration, most changes are disturbing. They require that teachers take risks in establishing new ways of relating to their students, they threaten the teacher's authority and pedagogic expertise in the classroom because they demand new ways of working with learners, and they often require a level of subject competence which teachers do not have. As a teacher in one of the case studies put it "it's pretty scary"

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

- \* Disequilibrium : teachers must themselves share a dissatisfaction with present programmes 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.
- \* Modelling: teachers have to be in touch with peers who are operating the innovation, and on whom they can initially model their own efforts.
- \* Support: teachers have to be given support, within their own district and particularly in their own school - a support which recognises that innovation cannot be risk free and which 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 whilst one is on one's feet trying to manage the situation - opportunity to sit back and reflect, alone and with colleagues is essential if lessons are to be learned from one's first struggles with an innovative approach.

## **The Students' Perspective**

This topic was in some ways similar to assessment, in that it was initially difficult to get many countries, in their reports on their innovative work, to produce evidence about the performance and the attitudes of their students. As more evidence on this aspect was produced, it became clear both that students could offer very useful insights on the processes of reform and that change could often be stressful and disorienting for them. The changes in the definition of the subjects meant, for those experiencing changes during the course of their school career, 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 could also be changed so that they would have to become accustomed to new ideas about what constitutes learning - and therefore learn to behave in quite new ways in their classrooms.

A science 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 analyse it Therefore, it is logical at this level that we should require them to follow a series of steps - always the same ones - in order to produce reports, and also that they should know that the reports are taken into account when we evaluate their performance.*

This extract illustrates a feature that was common across several reform programmes - that students needed particular help in assuming greater independence in their learning: such independence meant that they had to break the habit of having recourse to their teacher whenever they encountered uncertainty or difficulty.

One particularly significant and common change was that students had to learn, for the first time in most cases, to work through collaboration in small groups. Some responded positively, as illustrated in the words of this student from British Columbia: -

*I like working in big groups because I like to hear what people think, then we all come together and get a big idea on it... I think that's much better, because it helps you understand it better too.*

Others clearly encountered more difficulty, as in the case of this student from Spain: -

*I don't think that we work very well in groups. We are too used to having to listen. When we are told to work in groups, well it depends on what kind of day you're having and the mood people are in. In science, though, we are getting better and better at group work. But on the other hand, there is always someone who won't participate simply because he doesn't feel like it*

Some of the studies contain a wealth of evidence about students' reactions which cannot be fairly represented here. Overall this aspect of the case studies shows the importance of listening to the voices of students' as any reform or innovation is being put into practice for the first time.

## **Strategies for Change**

The relative neglect of work on assessment and on students' reaction was a symptom of a more general weakness in these studies. Whilst the innovations had clearly engendered fruitful changes and positive enthusiasm amongst those affected, none was accompanied by a thorough going programme of evaluation. Thus quantitative data, or even systematic qualitative data, on improvement in students' learning was not provided, and there were no attempts to reckon the costs of the changes and set these alongside a summary of the benefits performances

However, several common features do emerge fairly clearly. These may be listed briefly as follows

⌚ The common distinction between 'Top-Down' and 'Bottom-Up' reforms does not often apply; several had that originated from teachers was subsequently supported as a state initiative for widespread adoption.

\* Reforms cannot work if they are too radical; where procedures and targets are set up which are completely foreign to teachers, they will feel de-skilled and threatened, and may easily become demoralised and resistant; it is important rather to build on existing strengths as far as possible.

⌚ It take teachers and schools considerable time to adapt to reforms, particularly as they ought to adapt the change plans in the light of their first experiences of adopting them; it is both un-realistic and unhelpful to expect changes to succeed at the first attempt, and dangerously misleading to judge them harshly on the evidence of initial attempts to implement them.

\* Each reform should be considered in relation to the particular context of culture and tradition in which it is made concrete, which is to say that notwithstanding the analytic overview attempted in this paper, any reform should be regarded as an organic whole rather than as a machine made up of distinct working components..

\* The complex interactions implied by the previous point are an enduring feature: any change which works with one aspect only of an educational system will inevitably affect, and be affected, by other aspects, so a systemic approach has to be adopted in any planning.

The last of the above points is the most difficult of all to reckon with in planning or assessing changes. A systemic approach does not imply that any reform has to aim to change every possible aspect of an educational system - change would be hardly possible if this were true. The lesson is rather that any plan has first to consider the educational system in as broad and complex a manner as can be achieved. Then, in the light of this picture, a boundary has to be established for the proposed innovation ; all those elements inside the boundary will be tackled in a coherent and mutually supportive way by the innovation, whilst 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 on it.

Many tend to think of a systemic reform in terms of the machine as a metaphor - one characteristic of the age of 'the enlightenment'. This does not seem so useful for it implies a predictable and hierarchical model, where the grand design predicts and controls all that is to happen. A far more 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. Thus, studies such as the one described here can provide many useful insights, but they cannot produce ready-made

recipes for successful change. To invoke another metaphor, each innovation is like a play that has to be written for its own stage and audience - study of other plays can be no more than a useful guide to the creativity and craft of the playwright.

The picture that the studies paint of education in science, and in mathematics and technology, being re-defined and re-organised 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 which 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 re-consider 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.

Finally, I would like to suggest that an outstanding issue arising from these studies of change is that of authority over, and ownership of, school subjects. Changes of the type described in this paper are bound to worry those in higher education, because it will mean that the preparation of their students will be, at least, very different. But there is a broader implication. In the past it is the academics in (say) physics who had the right to decide the curriculum for school physics. In some countries, academics consult school teachers in such work. In other countries now, our innovations show that teachers are taking over - so that they are deciding what their students need. Who should decide? Do politicians, or citizen groups concerned about the uses and misuses of science, or those in business and industry where the majority of scientists actually work, have a right to a share in curriculum decisions? And if so, how are such rights to be exercised? And if such voices did have power, what might happen to physics education?

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Vol.2: *Cases in Science Education*

Vol.3: *Cases in Mathematics Education*

Published in hard-cover by Kluwer:Boston, available in soft-cover from The NETWORK, Publications, 300 Brickstone Square, Suite 900, Andover, MA 01810, USA.