From Quality in Learning, edited by John Stephenson and Susan Weil, published by Kogan Page, London in 1992.

CHAPTER SEVEN

CAPABILITY THROUGH SCIENCE AND MATHEMATICS

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The Context for Change

> ***Higher education courses in Science and Technology are...becoming less popular. For many students they provide an unsatisfactory intellectual and educational experience and an inadequate preparation for future jobs. The factual content which has been added over the years has become excessive leading to rote learning and insufficient understanding of fundamental principles.***
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> ***Many people who would benefit from higher education in Science and Technology, particularly mature students, cannot do so because of the lack of recognition given to non-traditional qualifications and insufficient practical support. (1)***

This is not a quotation from a group of trend setting educational theorists, but taken from the Report of the Manpower and Training Committee of the Advisory Committee on Science and Technology (ACOST) (1). ACOST is an advisory committee to the Cabinet. Its Manpower and Training Committee is made up of leaders of science based industry, university vice-chancellors, and senior government scientists. If mathematics had been part of its brief, it seems likely that it would have been included in its censure.

The ACOST Report recommends that

> ***higher education institutions implement procedures to audit teaching and place greater emphasis on teaching strategies that enhance understanding, investigative learning, and the development of originality and the funding councils should take into account the quality of teaching in assessing applications for funds.(1)***

A few months later, the Government White Paper, 'Higher Education: A New Framework' (2) embraced that recommendation. Funding for teaching is to be linked to quality as determined by quality assessment units set up in each of the three new funding councils for Britain. The units are to be staffed largely from HMIs and are likely to look for active teaching strategies of the type called for by ACOST. This is to be in the context of a massive increase in access, 50% over a decade, in which it is made clear that science and mathematics are expected to play a full part. The Labour Party policy document, 'Quality Assured' calls for similar changes (3).

It would be wrong to suggest that there is not much to be proud of in science and mathematics higher education. Despite criticism by at least some employers, science and mathematics graduates usually end up in fairly well rewarded employment. But as ACOST points out, science related subjects in higher education are becoming less popular and are attracting a disproportionately low share of non-standard entrants. ACOST is also correct in identifying the need to enhance understanding, investigative learning, and the development of originality. The White Paper sets this in the context of responding effectively to more and diverse students while maintaining, if not enhancing, quality.

Going beyond content coverage

Despite the strong case for capability approaches in general, some teachers of science and mathematics in higher education perceive considerable difficulties in introducing a capability approach in their subject area.

There are of course many substantial subject differences within the sciences and mathematics and care must be taken in generalising, but much of this apprehension appears to focus on content. The fact explosion continues. Each year scientists and mathematicians see more and more that they could/should/must include in higher education curricula. The pressures to include more and more content appear to be compounded by changes in schools-based teaching of science and mathematics.

Yet the domination of the curriculum by content is not inevitable. Bodies such as the Council for National Academic Awards and, before its demise, the University Grants Committee have repeatedly in science subject reviews expressed concern at the domination of curricula by factual content. Professional bodies such as the Institute of

Physics, the London Mathematical Society and the Royal Society for Chemistry are examining the question and finding that much of what one department finds essential is not taught, let alone learnt, in an apparently very similar department offering the same qualification. For example, it appears that the common content of Honours Chemistry Degrees in UK universities amounts to no more than 30% of what is taught in any one of them.

The differences in curricula are particularly notable in later years. For example, there is much similarity across English mathematics degree courses for the first year and a half, but overall, it seems that there is little consensus on what is 'essential', with much depending on the particular bias of the department.

The ACOST report also points to a limitation of access to higher education in the sciences and mathematics for those with non-traditional qualifications, particularly mature students. This perhaps results from a pre-established core of knowledge appearing to be an essential platform on which to build higher education in these areas. This seems to make conventional academic entrance qualifications more important and other experience relatively less so in these subjects.

Certainly the difficulties should not be underestimated. Science and mathematics do require a solid base on which to build. Much of science requires a solid basis of mathematics. This inevitably makes special demands on the non-traditionally qualified applicant.

Strategies for moving forward

What is important is that the difficulties are not seen as insuperable. In future, the differences between students - now called 'non-traditional' and 'traditional' - will become less pronounced. Departments will continue to recruit from schools, where through GCSE and SCE, BTEC and SCOTVEC, there are significant shifts away from the conventional 'academic' approach of A levels and Highers, but they must also recruit an increasing number of mature students lacking standard qualifications. Further challenges will be posed by the greater movement of students across the European Community and between and within institutions, with the growth of credit accumulation and transfer. Fresh thinking is needed about what is to be learned and why.

The assumption, generally implicit in many curricula, that the majority of science and mathematics graduates go on to become scientists or mathematicians, is increasingly being recognised as false. The majority, even of 'good' graduates, do not. Science and mathematics graduates go to a wide range of jobs. Even those who go into research typically use only a small proportion of the content conventionally seen as being so essential to their courses.

Employers too often find graduates lacking in problem solving skills and unable to communicate accurately and effectively orally or in writing.

The 'fitness for purpose' view of quality in the teaching and learning of science and mathematics must be taken seriously. We must think less in terms of the vocational needs of the training of research scientists and more of the general needs of employment and the broader development opportunities that can be offered by a scientific training.

Perhaps the position of science and mathematics, neither essentially vocational like medicine nor essentially non-vocational like the humanities, lies at the root of the misconceived view that there are special difficulties in introducing the development of capability through science and mathematics higher education.

Yet there is much in conventional science and mathematics courses which can be built upon. It is common for courses to include a major research project in the final year. Where this is the case, it is often observed that the rate of development of students undertaking such a project far outstrips that in earlier years. Increasingly, projects involve employers as external collaborators rather than being exclusively dependent on staff academic and research interests.

Understanding, communication skills, problem solving skills all rapidly develop within the context of such activity. The student shares responsibility for negotiating the project objectives with academic staff and any external collaborators. Project work can be introduced into earlier years of courses with similar benefits.

It is also being recognised that the traditional activity of students working in pairs in laboratories in the sciences and mathematics can be turned into group work with very little adjustment. Increasing group size and providing less structured experiments can help students to learn more explicitly about working in groups, leadership, communication, the use of critical analysis and judgment, and interpersonal skills development. This can involve learning contracts and self and peer group assessment, and encounters with unfamiliar problems that stimulate creativity and active inquiry skills.

Option courses, choices of experiments in laboratories, and case studies allow students to specialise within a subject while forming a ready basis for their playing a role in negotiating learning goals and outcomes. Without denying the need for a 'core' of necessary skills and fundamental knowledge, this process of negotiation can be begun much earlier in courses than is usual, giving students a sense of ownership over their learning from the outset.

Where it is possible, the introduction of work placements into the early years can give those with no work experience a context in which to set their learning. Such opportunities also allow those with previous work experience to build on that in ways that enhance motivation and involvement, as well as the understanding of core principles and pertinent theory. A period in another country provides similar benefits. Such activities may not have immediate vocational pay off, but contribute to the broader development of future scientists and mathematicians.

First year courses and pre-first year courses which develop scientific and mathematical skills, knowledge and understanding through a capability approach can considerably even things up for mature students with their greater life experience. Such initiatives also provide a more rewarding educational experience for the conventional entrant.

Such strategies can change the image of science and mathematics, and so help to attract and retain conventional and non-conventional entrants. Given the current financial cost to an institution of losing students in mathematics and sciences, these considerations will continue to be especially important if resources further diminish.

The introduction of capability principles and practices into science and mathematics courses in higher education must be taken through to assessment. It is not viable to expect students to work to develop skills and understanding which are not given full credit through assessment. We cannot expect to introduce the development of capability into the curriculum if in assessment we fall back on assessing rote learning of factual content. The introduction of capability concepts will normally involve introducing a substantial element of in-course assessment. The value of self assessment and peer assessment is also becoming recognised. The opportunities offered by assessment for enhancing student involvement, motivation, and the quality of their learning are considerable.

Below we describe a few examples of the capability approach which are currently working. Although we discuss them under the four Higher Education for Capability themes, it will be obvious that each example embodies more than one of the themes.

Theme One: Reviewing and Building on Experience

In science and mathematics there have been various attempts to respond to the greater diversity of intake. Perhaps because of the nature of the subjects there has been less straightforward building on life and employment experience. However efforts are made to enable students to see the links between science and mathematics and their own experience. The more usual approach is to provide a non-traditional start to a course where capability skills are strongly emphasised, leading students towards the more technical aspects which are taught by more conventional means.

The ***Polytechnic of East London {43}*** runs a HITECC foundation programme for students wishing to enter mathematics, science, engineering or technology. It is a one year full time (or equivalent) programme offered by the Continuing Education Department, a central services unit cooperating with all teaching departments. The underpinning learning philosophy is that excellence in knowledge acquisition and skills of analysis can be achieved only if capability skills are developed as an integral part of the subject.

The first six weeks of the course are spent in training and development in capability skills so that students have the tools to develop a capability perspective in their later studies and to take responsibility for their own learning. Skills which are developed include study time management, organising, decision making and oral and written communication, together with interpersonal leadership and team membership skills. Study methods include individual and group work, non-directed private study, practice in using resource based learning, case studies, simulations and closed circuit television.

This initial development of capability skills is followed by three further components: core mathematics and science; new technology appreciation; and a specialist study in mathematics, a science or an area of engineering. The programme content is student derived and managed. Students profile themselves, plan personal development paths and goals and demonstrate their achievement through negotiated in course assessment and final assessment in the form of a portfolio. Students can choose a recommended core content providing the prerequisite knowledge and skills required for any one of the 26 undergraduate courses to which the programme is linked.

The training in capability skills comes at the beginning of the course in order that students are enabled to manage their learning more effectively and to integrate capability skills into their knowledge acquisition. The core mathematics and science component, as well as the development of technical skills and knowledge, encourages further skills of personal organisation and time management through self paced and self managed resource based learning. Students also develop an ability to work without supervision. The new technology appreciation component helps to integrate the course with a student's life experience. The specialist study component has students working largely without supervision in a specialist teaching department, further developing self-reliance and confidence through working on projects and using specialist learning resources.

Approximately 25% of the course specifically cover general capability development and this is reflected in the balance of assessment; however, the capability skills acquired underpin learning throughout the course. Excellence of knowledge acquisition and skills of analysis are assessed in all four components through application of theory to practical situations and life examples. Breadth and depth of knowledge are not considered to be as important as the demonstration of understanding of the subject, its application and relevance to work and life.

This emphasis helps non-traditional entrants to bring some of their previous experience into their learning and so gain confidence. It provides an opportunity for converters, the unemployed and women returners, for example, to enter mathematics and science. Students who take the course are better prepared to manage the remainder of their undergraduate studies. At the Polytechnic of East London the course operates as a foundation programme. However many features of the approach, in particular the initial component developing capability skills, could be taken into a three year degree programme with great benefit to the learning throughout the remainder of the undergraduate programme.

A similar approach is adopted in the first year chemistry course in the Department of Applied Chemistry and Life Sciences in the ***Polytechnic of North London {145}*** **.**In the first seven weeks of the course there are no lectures. Students are invited to learn by addressing a number of questions. The material on which the questions are based is covered by set books so students have easy access to the information required for formulating answers. Negotiated targets are set for students.

The students' study is supported by tutorials where the emphasis is on student participation. The better prepared students produce high quality work in good depth; they are also generally very supportive to students with a weaker background, enabling these students to progress more rapidly and to tackle their learning in a far more effective way than would be possible if they were trying to learn on their own from lecture notes. The students with the stronger background move rapidly through the material they have already encountered and have greater opportunity to study more advanced material. Students are able to set their own pace.

Progress tests are used to inform students of their areas of strength and weakness and students can return to areas where further work is shown to be necessary.

After the first seven weeks, the remainder of the course is taught in a more traditional way through lectures and tutorials but there is still a component of self-learning material to support and reinforce the learning habits developed in the first seven weeks.

Later in the year a programme of guest speakers is organised. They talk on important topics of the day, for example chemistry and the environment or the place of the pharmaceutical industry in society. On the basis of these keynote speeches students develop their own talks on a theme of their choice. The talks are delivered to their fellow students and a written resume is produced. The majority of students are highly motivated by this, often seeing for the first time the interconnection between science, society and themselves. The students invariably produce well researched work.

Theme Two Planning, Negotiation and Approval

Examples of student negotiation and planning of their own learning in mathematics and science appear to be less extensive than in other subject areas. Perhaps this is because there is a conviction that there is an essential body of knowledge and skills which students must acquire, and that it is the teacher who is uniquely placed to define what should be learnt. However in some courses there is a degree of negotiation particularly on the rate of learning, but this can extend further. This is demonstrated by the above examples.

As noted above, in the HITECC programme at the Polytechnic of East London {43}, the form of both in course assessment and final assessment is the subject of student negotiation and this allows students to plan their personal development paths and goals. In the example from the Polytechnic of North London the targets set for students are the subject of negotiation and this allows students to move through the material at a pace which reflects their background and preparation.

In an interesting course which has been operating for the past three years in the Department of Applied Sciences at ***Staffordshire Polytechnic {203},*** science students and art students with a graphic design background are put into a customer-client relationship. The task is the development of a set of laboratory-safety videos and posters aimed specifically at young technicians. The science students work on the message and specification and negotiate the production with design students with the academic staff remaining very much at the periphery.

There is great scope for such cross subject projects involving inter-disciplinary teamwork. As well as fostering negotiation and planning between student groups, they strengthen teamwork, communication and inter-personal skills and provide an insight into another subject discipline.

Theme Three Active and Interactive Learning

There are a number of examples of the introduction of active learning methods into mathematics and science. This is perhaps because there is a well established tradition of final year research projects. It is increasingly becoming accepted that the learning advantages which come from these projects can also be gained through project work at all stages of a degree programme.

For example, at the ***University of Leicester {110}*** Department of Chemistry first year students are offered a range of approximately 30 projects in physical chemistry. Many of the projects require the use of sophisticated research apparatus. Each project involves making quantitative measurements and is designed to illustrate a key idea in modern physical chemistry. All are open ended.

Students tackle the projects in small teams. They are advised to spend the first week planning the project and assigning responsibilities and duties to members of the team. This develops students' planning and team working skills. The second and third weeks are spent carrying out the project. Although demonstrators are on hand, the students are encouraged to organise their own time. This develops leadership, self organisation and team work skills.

The fourth week is spent discussing results and preparing reports. Students help and teach one another as they argue through their experimental results. Each team produces a written report and a synopsis of the report which is displayed in the Department. In addition, each team presents its results in a seminar chaired by a member of staff. All first year students attend the seminar and all other members of the Department, staff and students, are invited to attend. Each member of the first year assesses each project with particular reference to communication and presentation. This assessment is combined with an assessment by a member of staff to give an overall assessment.

Students enjoy the team projects and appear to get a great deal from them. One student commented that for the first time she felt she was a real chemist - doing real experiments, not just routine experiments with well established results - looking up original and ?proper' papers in the library - talking to other chemists about what she had discovered.

The School of Applied Sciences at ***Wolverhampton Polytechnic {251}*** offers a module through which students develop and organise a control campaign in some area of medical or veterinary parasitology. The module is available to second and third year students. The scheme puts the whole emphasis of researching relevant information, synthesising a feasible solution and design of the campaign materials on to the students. Input from the lecturer is confined to encouragement and advice, rather than supervision. The students work in groups and so develop the skills of defining group objectives, assigning tasks and reporting back and thereby the skills of relating to others in the group, listening, arguing a case and accepting criticism.

Students agree a particular parasitological problem with the course tutors. They then determine the target of the campaign, for example, health workers, veterinarians, the general public, teachers, pet owners, livestock owners, etc., and the format of the campaign.The campaigns are based in an environment with which the students are familiar.

This approach allows extension of the normal academic process of learning the symptoms and cures for a disease to the practical application of this knowledge. Students are introduced to the problems encountered in applying scientific data to a specific problem. They learn by experience which data are essential and hence to be selective in the knowledge they acquire.

Students submit a rating of the performance of the contribution made by each of the other students in the group. These are averaged out and the mark awarded to the group by staff members is divided between the students according to this.

Each student is asked to produce a short report on their own development of capability skills and to comment on the project. In the main, students enjoy working on the project. They recognise that it improves their capability skills, notably in communication and group working and that it involves solving a real problem.

Theme Four Assessment

Assessment in mathematics and science has traditionally been rooted in the three hour examination with little, if any, weight given to in course assessment. Even in the laboratory based sciences, assessment of laboratory work has, surprisingly, usually made little contribution to final assessment. However, the examples suggest that attitudes to assessment are changing.

In first year Mathematical Sciences in the Department of Mathematics and Statistics at ***Paisley College {159}*** a Mathematical Sciences Laboratory has been established as a compulsory component of the course. A series of case studies is assigned to students. Students work on these in teams of three. They receive a problem, stated in non-mathematical terms, and are required to use mathematical methods and the computer to find a solution, finally producing a group report which describes the mathematical content used, together with an account of the group's solution, stated in non-mathematical terms. Each group of students is responsible for the organisation of its own work, in terms of discussing solution strategies, assigning among the members of the group responsibilities for carrying out investigations and experiments involving computer packages, and the production of the group's report, for which use of a word processor is encouraged.

The Mathematical Sciences Laboratory is assessed completely through in course assessment. This is based on individual laboratory reports and on the group study reports. Marks are awarded for quality of presentation as well as for mathematical content. This assessment contributes 30% of the mark for the first year Mathematical Sciences Course.

Problems with this type of assessment have emerged. Some students feel that marking is not uniform. It has proved difficult to eliminate this perception, as inevitably some tutors give more help than others, so that in some cases similar reports can merit different marks from different tutors. A partial solution has been to make detailed marking schemes available to tutors. Secondly, it can happen that resentments surface in certain groups, as some students contribute more than others. In such a case the solution has been for the group to negotiate with the tutor a weighting arrangement, whereby different members of the group receive different proportions of the marks.

The approach has proved popular with students and with employers. It has been particularly beneficial to students who were previously perceived as weak in mathematics.

The School of Health Sciences at ***Wolverhampton Polytechnic {253}*** runs a final year module in Applied Pharmacology and Toxicology. During the second half of the semester students undertake a special project using a combination of computer simulations and working as a project team to produce a pharmacodynamic and pharmacokinetic report on a range of drugs. Students work in groups and are required to produce a report of not more than 3000 words. The report is also presented orally to all students on the course with a time allowance of 30 minutes for presentation and 10 minutes for discussion. No credit is given for the oral presentation if the reports are simply read.

The project is assessed by a mixture of tutor assessment, intra group assessment and inter group assessment. The mark from the project contributes 50% to the overall practical assessment of the course. The group report is assessed by all staff teaching the module and the mark given for the report is allocated to each individual member of the group. In the intra group assessment each member of the group assesses each other member's performance and contribution to the work. In the inter group assessment, each group assesses the performance of the other groups in the oral presentation of the report. The group presentations are also assessed by the teaching staff. The overall assessment of the project is divided 30% for the staff assessed group report; 30% for intra group assessment; 20% for intergroup assessment and 20% for the staff assessed group presentation.

Conclusion

Enhancing the quality of learning

What becomes critical in sustaining student involvement and improving the quality of learning is the sense of ownership that students experience. While the 'taught' content may be reduced, experience such as that described above shows that the learnt content can be considerably greater; that the apparent conflict between content and process is illusory. Once what students learn, considered in the context of fitness for purpose, rather than what the teacher teaches becomes the focus of attention, many of the apparent problems begin to disappear.

Much is happening. As the examples above show capability ideas are being introduced into higher education courses in the sciences and mathematics though not always under that name: sometimes as enterprise, sometimes as transferable skills, common skills, or competences, and often under no banner at all but in response to the diverse needs of students as identified by themselves, by staff or by external organisations. But more is needed.

The introduction of capability or other student centred approaches does not offer science and mathematics higher education on the cheap. The opposite is likely to be the case. High quality education, whatever the level, does not come cheap. Adequate provision of resources in mathematics and sciences is essential. Quality and capability are not consistent with the 'teach 'em cheap, stack 'em deep' philosophy of education. There is, however, tremendous scope for re-thinking the use of existing resources to alternative ends, as evidenced by work in this volume.

No less, is the need for clear, explicit and public support from senior management. Institutional policies need to be reviewed. Time needs to be provided to allow fresh thinking, and staff development needs to be made a high priority. There are institutions where investment in research is seen to be more clearly valued than investment in teaching and learning. Staff may be persuaded that the quality of student learning may be enhanced through capability approaches, but considerable changes will be required to persuade staff that their investment in such initiatives is worthwhile in terms of their own careers.

Higher Education for Capability, while not ignoring the genuine problems of introducing capability principles and practices into science and mathematics higher education, does not accept that the problems are intractable. Experience shows that it can be done, as evidenced by the examples described above. The considerable activity within science and mathematics is now being collated by the RSA specialist network and data base. It is important that those who see the significance of these developments support each other, learn from each other and work together to convince doubting colleagues.

Scientific education in future will need to place value on creative and active inquiry, on awareness of oneself and of ones world, on working with others, and on continuous learning and development, as well as on the acquisition of specialist understanding and skills. The challenge is not only to develop scientists and mathematicians, but people with a scientific or mathematical education who can live and work in a rapidly changing world. There can be little doubt that graduates who combine technical subject based skills and knowledge with capability skills are what the nation needs and what employers increasingly are demanding.

Notes and references

(1) ACOST (1991) Science and Technology: Education and Employment. HMSO

(2) DES (1991) Higher Education: A New Framework. HMSO/Cmnd

(3) Smith, Andrew (1991) Quality Assured: labour's proposals for safeguarding and enhancing quality in higher education. The Labour Party.