Towards a Science Education for All: The Role of Ideas, Evidence and Argument

Jonathan Osborne
Beyond 2000
science education
for the future

1999
Beyond
2000
2001

a report with
ten recommendations
Trends in A-Level Numbers

- Physics
- Chemistry
- Biology
- Maths
- 2 per. Mov. Avg. (Physics)
Physics could be in "terminal decline" - FT p4

The death of physics - Mail p47

Physics in downward spiral as pupils think it is too difficult

Teaching of physics in steep decline - Telegraph p8
‘Third World Britain’ will fail to train scientists

BY STEPHEN HULL

BRITAIN is rapidly becoming a ‘Third World country’ because of its failure to produce scientists and engineers, independent schools warned yesterday.

Jonathan Shephard, head of the Independent Schools Council, said ministers need to work with private schools to rescue the situation.

Countries such as India and China are producing tens of thousands of engineering graduates and mathematicians every year while numbers studying these courses in Britain have plummeted, he added.

Speaking at the Headmasters’ Conference in the West Midlands, Mr Shephard called on the Government to harness resources private schools could offer.

He said: ‘Despite a number of improvements in state school results, the decline in maths, sciences, engineering and modern languages is insupportable and has to be reversed. Otherwise we are heading rather rapidly towards Third World status.’

Since 1997, when Labour came to power, the number of students studying many of these key subjects at university has fallen dramatically, Mr Shephard said.

The problem has also affected language teaching, where ministers changed the law so that it is no longer compulsory to study a language at GCSE level – a decision headteachers’ leaders condemned.
'Australia’s ability to prosper in this environment depends on high levels of R&D. These in turn require that more young people achieve scientific and technical qualifications with a strong base in the physical and biological sciences and mathematics. By itself, this will not be enough. Policies and strategies are required to ensure a broad base of scientific, mathematical and technological literacy for all students. This means that science, technology and mathematics education must be given high priority nationally, in all education systems and every school.'
RISING ABOVE THE GATHERING STORM

Energizing and Employing America for a Brighter Economic Future

EXECUTIVE SUMMARY
✧ Last year, more than 600,000 engineers graduated from institutions of higher education in China, compared to 350,000 in India and 70,000 in the United States.

✧ Recently, American 12th graders performed below the international average for 21 countries on general knowledge in math and science.

✧ The cost of employing one chemist or engineer in the United States is equal to about five chemists in China and 11 engineers in India.

✧ Chemical companies last year shut 70 facilities in the United States and marked 40 for closure. Of 120 large chemical plants under construction globally, one is in the United States and 50 are in China.
Europe needs more scientists

Report by the High Level Group on Increasing Human Resources for Science and Technology in Europe 2004
## English Students’ Attitudes to Science

<table>
<thead>
<tr>
<th></th>
<th>Disagree</th>
<th>Low Disagree</th>
<th>Low Agree</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would like to become a scientist</td>
<td>58%</td>
<td>21%</td>
<td>13%</td>
<td>8%</td>
</tr>
<tr>
<td>I like school science better than other subjects</td>
<td>43%</td>
<td>25%</td>
<td>20%</td>
<td>11%</td>
</tr>
<tr>
<td>School science is interesting</td>
<td>16%</td>
<td>23%</td>
<td>38%</td>
<td>23%</td>
</tr>
</tbody>
</table>

I like school science better than most other school subjects.

In many countries, girls seem to dislike school science.

In many industrialized countries, science is less popular than other subjects.
What would you like to learn about?

- 108 Items
- No less than 80 generated statistically significant differences between girls and boys

Boys

1. Explosive Chemicals
2. How it feels to be weightless in space
3. How the atomic bomb functions
4. Biological and Chemical Weapons and what they do to the human body
5. Black holes, supernovae and other spectacular objects in space

Girls

1. Why we dream when we are sleeping and what the dreams may mean
2. Cancer, what we know and how we can treat it
3. How best to perform first-aid and use basic medical equipment
4. How to exercise to keep the body fit and strong
5. Sexually transmitted diseases and how to be protected against them.
Overview

- What change necessary?

- What should be the goals of a science education for all?

- What contribution can the exploration of ideas, evidence and argument make?
History of Reform

• Armstrong - the Heuristic Method

• Dewey - learning a student-centred process of enquiry

• Schwab - taught as ‘enquiry into enquiry’

• Nuffield Reforms in the UK

• Science as a Process
More Recent Developments

• UK - National Curriculum
  ❖ 4 Versions since 1989!

• USA - National Science Education Standards

• UK - How Science Works
School Science: The Essential Tension

- Science Education as an *Education*
  - Science as a Way of Knowing
  - Conceptual Coherence
  - Preparation for Citizenship
  - Science as a Cultural Achievement

Versus

- Science Education as a Pre-Professional *Training*
  - Authoritarian
  - Foundationalist
  - Atomised
To borrow an architectural metaphor, it is impossible to see the whole building if we focus too closely on the individual bricks. Yet, without a change of focus, it is impossible to see whether you are looking at St Paul's Cathedral or a pile of bricks, or to appreciate what it is that makes St Paul's one the world's great churches. In the same way, an over concentration on the detailed content of science may prevent students appreciating why Dalton's ideas about atoms, or Darwin's ideas about natural selection, are among the most powerful and significant pieces of knowledge we possess.

(Millar & Osborne, 1998:13)
But if all these examples of our cosmic connectedness fail to impress you, hold up your hand. You are looking at stardust made flesh. The iron in your blood, the calcium in your bones, the oxygen that fills your lungs each time you take a breath—all were baked in the fiery ovens deep within stars and blown into space when those stars grew old and perished. Every one of us was, quite literally, made in heaven.

Liberal Vision of Science Education

- Freed us from the shackles of received wisdom
- Knowledge derived from evidence and rational thinking
- Offers a defense against mere assertion
- A route to intellectual autonomy
- Distinctive way of knowing
Science for Citizenship

• Any education in science must attempt to communicate not only what is worth knowing but how such knowledge relates to other events, why it is important and how it came to be.

• Most of what non-scientists need to know in order to make informed public judgements about science fall under the rubric of history, philosophy, and sociology of science, rather than the technical content of scientific subjects.

• Ryder: most of the science within contemporary scientific controversies is not addressed by school science.
How Science Works

- Scientific Methods and Critical Testing
- The Role of Creativity in Science
- Historical Development of Scientific Knowledge
- Science and Questioning
- The Diversity of Scientific Thinking
- The Relationship between Science and Certainty
- The Role of Hypothesis and Prediction
- The Role of Competition and Collaboration

Enabling Democratic Participation

Democracy functions by majority decision on major issues which, because of their complexity, require an increasing amount of background knowledge. For example, environmental and ethical issues cannot be the subject of informed debate unless young people possess a certain scientific awareness. At the moment, decisions in this area are all too often based on subjective and emotional criteria, the majority lacking the general knowledge to make an informed choice. Clearly this does not mean turning everyone into a scientific expert, but enabling them to fulfill an enlightened role in making choices which affect their environment and to understand in broad terms the social implications of debates between experts.
A victim of smallpox
Gloucester 1923
Deaths from Infectious & Respiratory Diseases 1920-2000 (UK)
How do we Know?

• That Day and Night are caused by a spinning Earth

• Arguments Against:
  1. The Sun moves
  2. If you jumped up you would not land in the same spot
  3. If the Earth was spinning at that rate, the speed at the equator is over a 1000 mph and you should be flung off.
  4. There should be an enormous wind as the atmosphere lags behind.
The Elements of a Science Education

- **Conceptual**
  - Developing Knowledge is an Interactive Process

- **The Epistemic and Social Practices** of Science

- **Cognitive**
  - Goal of developing intellectual autonomy
  - Value as a pedagogic heuristic

- **The Affective and the Social**
The Conceptual Value of Argumentation

• Past decade a body of work has emerged exploring the teaching of ideas, evidence and argument.

• Leads to enhanced conceptual understanding
  - Alverman and Hynd
  - Zohar and Nemet

  • ‘integrating explicit teaching of argumentation into the teaching of dilemmas in human genetics enhances performance in both biological knowledge and argumentation’
Participants who were asked to argue in favour of an alternative explanation of a physics problem (the scientific explanation) were more likely to show improved reasoning on the problem than control participants who were asked to solve the problem without argumentation.

What Evidence?


- Seven Classes of Children in Year 5
- 12 Detailed Lessons
  - Teacher led introduction
  - Group Discussion Activity
  - Final plenary session
  - Set of control classes
## Data from Performance on SATS (Age 11)

<table>
<thead>
<tr>
<th></th>
<th>Numbers</th>
<th>Pre-Intervention Mean Scores</th>
<th>Post Intervention Mean Scores</th>
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<tbody>
<tr>
<td><strong>Target Classes</strong></td>
<td>119</td>
<td>3.97</td>
<td>5.70</td>
</tr>
<tr>
<td><strong>Control Classes</strong></td>
<td>129</td>
<td>4.22</td>
<td>5.04</td>
</tr>
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</table>

\[(F (1,245) =10.305; \text{two tailed } p-0.002. \text{ Effect Size } = 0.29)\]
Research on the Cognitive Outcomes of Engaging in Argument and Dialogue

• **Kuhn**

• **Zohar**

• **Howe**

• **Osborne, Erduran & Simon**
Results: Osborne, Simon & Erduran

Levels of Argument
Improved Satisfaction with Learning


‘it is clear from these data in these classrooms where students perceive their science teacher as interested in student understanding and independent thinking, rather than in the speedy recitation of correct answers, students are more likely to have productive and satisfying learning experiences.’
Science for Public Understanding: Students’ Perceptions of the Course

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<tbody>
<tr>
<td>Enjoyable</td>
<td>62</td>
</tr>
<tr>
<td>Interesting</td>
<td>74</td>
</tr>
<tr>
<td>Easy</td>
<td>47</td>
</tr>
<tr>
<td>Different</td>
<td>65</td>
</tr>
</tbody>
</table>

KS4 Science structure

Science (core)
10% curriculum time
Emphasis on scientific literacy
(science for citizenship)

Additional Science
Ge ‘General’
10% curriculum time

Additional Science
Ap ‘Applied’
10% curriculum time

ALL students do this (1 GCSE)

SOME students also do Ge or Ap (1 GCSE)
Mean
21st Cen Sci = 2.94
Stan GCSE = 3.02