

A CURRICULUM FOR EXCELLENCE REVIEW OF RESEARCH LITERATURE

SCIENCE EDUCATION

**Compiled by
Dr Donald Gray
University of Strathclyde**

Science Education continues to undergo a critical examination. While science education has traditionally been associated with a formal academic type of schooling, the intention of which has been to produce future scientists, a number of articles and reviews have critically questioned whether this is sufficient for the needs of both society and the citizens who are part of that society (Millar and Osborne, 1998; SCCC, 1996). The House of Commons Science and Technology Committee Report on Science Education 14-19 (HOCSTC, 2002) found that the science curriculum was “inflexible, irrelevant, repetitive and prevents debate” (p15), while the report was specifically referring to the English curriculum, the debate on what a suitable curriculum should consist of has been considered in the past in Scotland. The Scottish Consultative Committee on the Curriculum, responding to growing awareness of the need for an increasing public understanding of science and a more scientifically literate citizenry, established a Science Review Group, the remit of which was to go beyond immediate concerns over quality and effectiveness of provision, to consider broader questions about “the nature of science and the science component of the curriculum” (SCCC, 1996, p4). The result of the Science Review Group’s deliberations was to define science in terms of scientific capability which consisted of five distinct aspects: scientific *curiosity* – an enquiring habit of mind; scientific *competence* – ability to investigate scientifically; scientific *understanding* – understanding of scientific ideas and the way science works; scientific *creativity* – ability to think and act creatively; and scientific *sensitivity* – critical awareness of the role of science in society, combined with a caring and responsible disposition.

A similar report in England and Wales, *Beyond 2000: Science Education for the Future* (Millar and Osborne, 1998), concluded that the National Curriculum for England and Wales had failed to meet the needs of contemporary society, much less anticipated the needs of future society. The authors acknowledged that ‘the changing curricular position of science has not been accompanied by corresponding change in the *content* of the science curriculum . . . This has remained fundamentally unaltered and is, essentially, a diluted form of the 1960s GCE curriculum’ (p.4),

The report goes on to give ten recommendations which include that there should be more emphasis on technology and the applications of science; greater attention should be given to the social processes used to generate, test and scrutinize knowledge claims; teachers should employ a wider range of teaching and learning approaches, including the use of case studies of historical and current issues; new and broader approaches to assessment should be devised and implemented in order to focus attention on the more important

aspects of learning. As Hodson (2003), however, points out “*Throughout the document, the case for the importance of scientific literacy (largely defined in terms of conceptual and methodological knowledge, with some sociocultural dimensions) is strongly and repeatedly made, thus reinforcing the view of some critics that this is yet another attempt to rescue a conventional science education in crisis rather than a commitment to radically reshape the nature and purpose of the curriculum.*” (p650)

Hodson (2003) examining the science curriculum from a Canadian perspective, but dealing with issues of global concern, stated, when referring to the SCCCs report in largely positive terms, “*it is interesting and extremely disappointing that a document purporting to be action-oriented does not include preparation for sociopolitical action by students in its definition of scientific capability*” (p653). However, it should be noted that Hodson’s view of the necessary changes to the science curriculum to be one geared to socio-political action which equips “*students with the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental and moral-ethical concern*”, is a position which, while not restricted to him (Roth and Desautels, undated, Roth & Desautels, 2002) is, in Hodson’s own words “*...likely to be disturbing to science teachers, severely testing both their competence and confidence. Traditionally, science education has dealt with established and secure knowledge, while contested knowledge, multiple solutions, controversy and ethics have been excluded.*”

Aikenhead (2003), in his review of research on humanistic perspectives in science curricula, concludes that students do positively respond to and can learn usefully from humanistic science curricula but that there are paradoxes and trade-offs evident from the research. Thus he observes that relevant contexts alone do not ensure more learning of science; that values and self-identity necessarily count; where there are contentious issues, the more important the values the less important the content; the more explicit the instruction and the assessment regarding humanistic content, the better the learning, but the greater the challenge to teachers and teaching. Aikenhead suggests that we should be cautious in believing that the minority of students intent upon specializing in science (‘pipeline’ students) will respond to humanistic science. In his discussion of the implications of the research he so carefully reviews, he remains concerned over the fundamental dilemma as to whether science courses should serve humanistic ends (general educational ends, akin to those served by other subjects in the school curriculum) or whether they should continue to feed ‘the pipeline’. Aikenhead wants researchers to amalgamate the educational and the political to ensure that real progress will be made; consensus-making research and development on a reasonable scale is essential.

So, while on the one hand there is a debate about the future purpose of science education and whether it should be viewed largely in terms of creating a suitably trained workforce, or a critical thinking citizen, on the other hand there is a continuing examination of what learning and teaching strategies are considered to be effective. However, while there appear to be some common themes relating to pedagogy emerging from the literature, it is important to recognise that classrooms and schools are complex environments each of

which can be very different, in terms of social mix, general ability, teacher understanding, attitude and values, school ethos etc. The unique combination of these factors can make the use of prescriptive pedagogies unreliable. The approach adopted has to be appropriate to the unique environment of each classroom and the aptitudes of the teachers and students in that classroom. It is also the case that the pedagogies employed will be largely determined by the nature of the curriculum proposed. The type of approaches required to learn the periodic table are unlikely to be the same approaches which will develop higher order metacognitive and critical thinking skills.

As pointed out by Hoban (2002, p26): “In contrast to a mechanistic view of teaching as a ‘craft’ or ‘labour’ that can be mastered, a conception of teaching based on complexity theory acknowledges the dynamic context of each classroom and accepts that there is no such thing as fail-proof teaching strategies.”

In the very short time available for this review, a number of sources were accessed and examined. These include those referred to above but also a number of other larger scale literature reviews which were conducted for similar situations in other countries. The most notable of these is that carried out by Hipkens et al. (2003) for the Ministry of Education in New Zealand. This report is extensive in its scope and amounts to 270 pages, too much to summarise in a few short pages. However, key aspects of the report were dealt with in a special issue of the International Journal of Science Education (v.27, n2, 2005) and these articles provide useful summaries. However, in addition, a number of other publications are referred to, including a review of Effective Teaching in Science carried out by Wynne Harlen (1999) in the Scottish Council for Research in Education on behalf of the Scottish Office Education Department, and Improving Achievement in Science in Primary and Secondary Schools (HMIE, 2005)

Key issues emerging from the literature which have a direct bearing on the curriculum, as well as implications for pre-service education and in-service professional development are:

Nature of science – teachers’ and students’ understanding. Much of the literature suggests that many teachers’ understanding of the nature of science is implicit rather than explicit (Hipkins et al. 2003), sometimes naive and at odds with established wisdom and understanding. Thus the way in which science is portrayed to school students focuses very much on science as a body of “facts” and a methodological approach and very often fails to address the tentative nature of science, uncertainty and unpredictability in science and the way in which values, attitudes and cultural perspectives can influence both the practice and interpretation of scientific activity.

Cognitive and metacognitive thinking skills. The way in which science is traditionally delivered in most schools relies heavily on transmissive modes of teaching with a heavy emphasis on practical work. Research has shown that such approaches fail to develop critical thinking skills nor metacognitive abilities. While there is increasing attention been given to this, particularly with the introduction of initiatives like CASE (cognitive acceleration through science education), science education is, nevertheless still felt to be

delivered in ways which do not develop such skills. Group work and peer discussion have been identified as important ways of enhancing students' cognitive and metacognitive thinking skills (Coll, France and Taylor, 2005). Findings from a substantial body of research suggest that more metacognitive approaches to pedagogies which use models, metaphors and analogies could be a practical and manageable way to integrate cognition and metacognition in classrooms at both primary and secondary levels (Hipkins et al. 2002).

Interactive activities including **discussion** and **collaborative learning** (e.g. McGregor 2004, HMIE, 2005) While the benefits of interactive approaches to science education, which may include use of appropriate ICT, has been shown to be beneficial, there is some evidence that science teachers are unfamiliar and uncomfortable with such approaches.

As Bell (2005) states, *“the effectiveness of discussion in small groups in promoting conceptual development was evaluated positively in [a number of] theses of NB None of the references in this para are listed, therefore I suggest they should be omitted. The discussions usually emerged during a specific and planned activity such as card-sorting), crosswords , task sheets) practical work, rock sorting and booklet discussion task). It was not the activity per se that promoted the learning, but the language and thinking involved in completing the activity”*.

Classroom research, and evidence from the TIMSS and PISA studies suggests that engaging and effective science learning require students to be actively involved in discussion, model-building and testing, questioning their understanding of concepts, learning about the relationship between evidence and theory, and so on. This kind of learning requires much interpersonal interaction and communication. Since interpersonal interactions have the potential to be interpreted differently by the various participants in the interaction, the pedagogical significance of communication issues in science teaching and learning is strongly underlined (Jones and Baker, 2005; Rivard, 2004; and Rivard and Straw, 2000).

Practical work. Science education has traditionally had a heavy emphasis on practical work but evidence suggests that it is not used effectively and that it often fails to achieve the intended learning outcomes. Research highlights the need for teachers and students to consider practical work as a thinking activity in which each participant constructed understandings, rather than solely the domain of the manipulative work of the hands. This is in sharp contrast to the predominant view of process skills often promoted in the secondary science syllabus. Some of the evidence from the classroom based research points to non-achievement of intended outcomes, in particular when either “recipe” practical work or “fair testing” is the predominant pedagogy employed (Hipkins et al., 2002).

Informal and out of school learning situations (museums, science centres, outdoor centres) The recent review carried out by Kelly (2000) described 141 studies that have investigated various learning outcomes from science centre visits, including those relating specifically to visiting school groups (Rennie and McClafferty, 1996). Studies confirm that these visits can provide valuable and often motivational opportunities for students to learn science. It is well documented that informal learning experiences can

sometimes be more effective than formal schooling in bringing about awareness of issues, attitudinal shifts and willingness to engage in action (Ramey-Gassert and Walberg, 1994; Rennie and McClafferty, 1996; Jeffrey-Clay, 1999; Pedretti, 2002). Informal learning experiences are particularly well positioned to facilitate the affective and social components of learning (Alsop and Watts, 1997; Meredith, Fortner and Mullins, 1997). As stated by Barker et al. *“the evidence in support of the educational impacts of fieldwork on children is conclusive (eg. Bogner, 1998; Nundy, 2001), but is largely focused on younger children. There is also clear evidence in other areas of education that a mix of teaching and learning approaches – including ‘hands-on’ and differentiated learning, which characterises much outdoor teaching – does help to meet the needs of the whole class. It also helps to motivate and inspire children who may otherwise be sidelined by a more formal classroom situation (Nundy, 2001)”*.

Moral, ethical and social dimensions of science. While there is growing recognition of the need to address the moral and ethical issues which we are confronted with as a result of scientific progress, evidence suggests that many science teachers do not feel comfortable, nor equipped to deal with these issues (Levinson and Turner, 2002 ; Bryce and Gray, 2004). Knowing how to handle discussion and debate in the class is an area which needs to be developed in the science classroom (Newton et al., 1999). Research points out the importance of teaching science in real contexts in order to engage students interest, to increase the relevance of science to students’ lives, and to help students develop better understandings in science and about science (Jones and Baker, 2005).

Related to the moral, ethical and social aspects of science are the **local and global implications** of science issues and how, as well as being important for the development of scientific literacy and citizenship skills, they provide real-life contexts for the study of scientific knowledge as well as providing relevance and motivation for the students engaged in their study (Colucci-Gray et al., in press; Carter, 2005; Hodson, 2003). In addition there is a growing body of literature which suggests that the current science curriculum is dominated by “western” science and more acknowledgement should be given to science derived from other cultures as well as indigenous science e.g. (Hipkins, 2002; Snively and Corsiglia, 2001).

Professional development. Given the discussions which are taking place in the literature about what a science curriculum relevant to today and for the future might consist of, there is also a growing awareness that the many of the teachers currently teaching science will require new skills, knowledge and understanding in relation to the science, the impact of science and society, the nature of science and new pedagogies related to discussion, collaborative learning, interactive pedagogies and strategies for developing metacognitive skills in students (Hipkins et al., 2003; Hodson, 2003; Bryce and Gray, 2004). Similarly there is a requirement for **pre-service education** to address these issues. However, while there is a growing body of literature in relation to these issues, there is still a need for further research to examine new pedagogies and the approaches to science education which are required to fulfil multiple purposes and outcomes which have not hitherto been considered a part of the traditional science curriculum

Primary/secondary transitions and progression. The HMIE report, *Improving Achievement in Science*, stressed the importance of cooperative working between primary and secondary schools to ensure progressive development of knowledge, understanding and skills, particularly investigative and thinking skills. It also emphasises the importance of interactive approaches to learning and teaching and should encourage discussion of social, moral and ethical issues as well as including key areas of contemporary science to help prepare all young people for the science they will encounter as citizens of the 21st century. While primary/secondary transition has often been identified as a problematic area, Galton (2002) suggests that improvement of this has less to do with changing the curriculum and more to do with the way that the existing curriculum is taught with more attention being paid to establishing greater continuity in teaching by building more effectively on what has been started in primary schools. While Davies' (2004) study suggests that, "*as a result of joint planning and implementation of a bridging unit, there had been an increase in the secondary school teachers' understanding of both the range of the science curriculum covered in primary schools and pupils' levels of attainment in the procedures of scientific enquiry. There was also evidence that transfer assessment information was informing planning and that pupils were experiencing greater continuity in their science education*". Galton suggests giving "*less attention to the production of curriculum materials, as with the current emphasis on the use of bridging units, and to pay more attention to establishing greater continuity in teaching (approaches)*".

Assessment One of the key problems to be addressed is that of assessment. While, some recent work has contributed significantly to this (Black and Wiliam, 1998), much of the assessment pupils are likely to encounter in a secondary science class is based on exercises and tasks that rely heavily on memorisation and recall, and are quite unlike those contexts in which learners might wish to use science knowledge or skills in later life (Millar and Osborne, 1998).

General Pedagogical Issues

Collectively, the research suggests that such students may experience more success where classroom pedagogy incorporates as many as possible of the following features:

- Teachers use pedagogy that raises their own and the students' awareness of the range of ideas about a phenomenon, situation or learning process, and these ideas are taken into account when planning and carrying out learning experiences.
- Learning experiences are set in familiar and/or personally meaningful contexts and students are aware of purposes for the learning.
- Learning helps students to build a wide range of rich experiences of the world around them, especially in the earlier years of school.
- Students frequently engage in purposeful dialog with the teacher and/or with groups of their peers. Conversations are scaffolded by the teacher, with explicit modelling of the type of discourse that is appropriate and of the type of outcome/product to be achieved. This also enables teachers to engage in strong formative interaction to help students as they learn.

- Teachers routinely use basic literacy strategies to help students to decode text and to cope with the specific features of science text that create additional barriers for those who need literacy support. Pedagogies that require students to read and/or write as part of the learning are varied but have in common that they actively engage students' own thinking.
- Less 'content' is introduced at any one time, so that it can be more fully explored. Content and learning experiences are used in ways that are relevant to students' lives beyond school.
- Teachers help students to build bridges between their own life worlds and the cultural world(s) of science.
- Students whose first language is not English are given opportunities to discuss their learning in their first language where possible. (Jones and Baker, 2005, p140)

Hipkins et al. (2002) in examining the research literature on learning and teaching in science for the Ministry of Education in New Zealand suggest implications in three broad areas. While the third of these specifically mentions New Zealand, the issues are likely to be just as pertinent to the Scottish situation.

1) Professional development and pre-service teacher education.

- To conceptualize and plan for meeting a wider range of purposes for learning in science, teachers need to develop deeper understandings of the nature and characteristics of science and, in some cases, a richer pedagogical content knowledge to draw on when teaching science.
- Basic literacy strategies and knowledge of the particular challenges of reading and writing in science need to be part of every teachers' pedagogical content knowledge.
- Science teachers at the secondary level may need support to become confident in using pedagogies for the purpose of drawing out and exploring a range of student ideas and opinions.
- New strategies such as the use of narrative in science learning are likely to be unfamiliar to many teachers. With increasing familiarity and confidence in these strategies, existing curriculum resources could be better utilized than is currently the case.
- Developing teachers' knowledge requires enough time for in-depth engagement with these ideas and the opportunity to develop conceptual frameworks that they can successfully apply in their teaching. The short length of pre-service teacher education programs and sporadic opportunities for in-service teacher development in science education needs to be addressed.

2) Curriculum.

- Wide dialogue about the purposes for learning science could unsettle the usual practice of 'science for the preparation of future scientists' as the main purpose of science learning for all students.
- Curriculum content reduction could ease the imperative of 'curriculum coverage' that appears to constrain the use of the well-researched wide range of successful classroom pedagogies.

- Curriculum should not dictate pedagogy, but should reflect characteristics of the subject and allow for effective pedagogies to be realized. There needs to be an alignment of curriculum content with the pedagogies recommended in this review—the question is how best to operationalize the curriculum in the classroom through effective pedagogy. It is recommended that the existing curriculum be audited to see where it can be developed and fine-tuned in view of these recommendations.

3) Long-term, sustained classroom research is needed:

- to investigate how students' progress in learning science;
- to investigate teachers' beliefs and perceptions about the nature and characteristics of science and the purposes of science education;
- to investigate current classroom practice to understand how the effective pedagogies discussed in this review might be realized in classrooms;
- to develop strategies for introducing the key ideas to emerge from this review
- to pre-service and in-service teachers and teacher educators;
- to aid the development of systems to support and evaluate the introduction of these ideas and their associated pedagogies in classrooms;
- to assess the impact of these pedagogies on the science curriculum experienced by students and on students' perceptions and beliefs about science; and
- to assess the impact of these pedagogies on the engagement and achievement of all students.

References

- Aikenhead, G. S. (2003). Review of Research on Humanistic Perspectives in Science Curricula. Noordwijkerhout.
- Bell, B. (2005). Pedagogies developed in the learning in Science projects and related theses. *International Journal of Science Education*, **27**, 159-182.
- Black and Wiliam (1998) Inside the Black Box. Raising Standards through Classroom Assessment, London, Kings College.
- Blank, L. (2000). A metacognitive learning cycle: a better warranty for student understanding? *Science Education* **84** (4) 486-506.
- Bryce, T. G. K. and Gray, D. (2004). Tough acts to follow: the challenges to science teachers presented by biotechnological progress. *International Journal of Science Education*, **26** (6), 717-733.
- Carter, L. (2005). Globalisation and Science Education: Rethinking Science Education Reforms. *Journal of Research in Science Teaching* **42** (5), 561-582.
- Coll, R. K., France, B., and Taylor, I. (2005). The role of models/and analogies in science education: implications from research. *International Journal of Science Education*, **27**, 183-198.
- Colucci-Gray, L. C. E. B. G. and. G. D. From scientific literacy to sustainability literacy: an ecological framework for education. Science Education.
- Davies D. (2003). Pragmatism, Pedagogy and Philosophy A Model of Thought and Action in Action in Primary Technology and Science Teacher Education. *International Journal of Technology and Design Education*, **13** (3), 207-221.
- Davies, D. and McMahon, K. (2004). A smooth trajectory: developing continuity and progression between primary and secondary science education through a jointly-planned projectiles project. *International Journal of Science Education*, **26**, 1009-1021.
- Galton, M. (2002). Continuity and progression in science teaching at Key Stages 2 and 3. *Cambridge Journal of Education*, **32** (2), 251-265. Carfax.
- Harlen, W. (1999). *Effective Teaching of Science: A Review Of Research*. Edinburgh, Scottish Council for Research in Education.
- Hipkins, R., Bolstad, R., Baker, R., Jones, A., Barker, M., Bell, B., Coll, R., Cooper, B., Forret, M., Harlow, A., Taylor, I., France, B. and Haigh, M. (2002). *Curriculum, Learning and Effective Pedagogy: A Literature Review in Science Education*. Auckland: New Zealand, Ministry of Education.
- HMIE (2005) *Improving Achievement in Science in Primary and Secondary Schools*. Livingston: HMIE
- Hoban, G. F. (2002). *Teacher Learning for Educational Change*. Buckingham: Open University Press.
- HOCSTC. (2002). *Science Education from 14 to 19*. 1. London, House of Commons, Science and Technology Committee
- Hodson, D. (2003). Time for action: science education for an alternative future. *International Journal of Science Education*, **25**, 645-670.

- Hudson P. (2004). Toward Identifying Pedagogical Knowledge for Mentoring in Primary Science Teaching. *Westminster Studies in Education* **13** (2), 215-225.
- Jones, A. and Baker, R. (2005). Curriculum, learning and effective pedagogy in science education for New Zealand: introduction to special issue. *International Journal of Science Education*, **27**, 131-143.
- Kelly, J. (2000). Rethinking the elementary science methods course: a case for content, pedagogy, and informal science education. *International Journal of Science Education*, **22**, 755-777.
- Kolsto, S. D. (2001). Scientific literacy for Citizenship: tools for dealing with the Science dimension of controversial socioscientific issues. *Science Education*, **85**, 291-310.
- Lederman, N. G. (2001). A Partial List of the Empirical Theoretical Literature on Subject-Specific Pedagogy. *School Science and Mathematics*, **101** (2), 61-80.
- Levinson, R. and S. Turner (2001). *Valuable lessons*. London: The Wellcome Trust.
- Millar, R. and Osborne, J. E. (1998). *Beyond 2000: Science education for the future*. London: King's College London, School of Education.
- Newton, P., Driver, R., and Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education* **21** (5), 553-576.
- Pedretti, E. (2002) T. Kuhn meets T. Rex: Critical conversations and new directions in science centres and science museums. *Studies in Science Education*, **37**, 1-42.
- Ramey-Gassert, L. and Walberg, H. J. I. (1994) Re-examining connections: Museums as science learning environments. *Science Education*, **78**, 345-363.
- Rennie, L. J. and McClafferty, T. (1996) Science centres and science learning. *Studies in Science Education*, **27**, 53-98.
- Rivard, L. P. and Straw, S. B. (2000). The effect of talk and writing on learning Science: an exploratory study. *Science Education* **84**, 566-593.
- Rivard, L. P. (2004). Are Language-Based Activities in Science Effective for All Students, Including Low Achievers? *Science Education* **88** (3), 420-442.
- Roth, W.-M. and Desautels, J. (undated). *Educating for Citizenship: Reappraising the Role of Science Education*.
- Roth, W.-M. and Desautels, J. (2002). *Science education as/for sociopolitical action*. New York: Peter Lang.
- SCCC. (1996). *Science Education in Scottish Schools: Looking to the Future*. Dundee, Scottish Consultative Council on the Curriculum.
- Snively, G. and Corsiglia, J. (2001). Discovering Indigenous Science: Implications for Science Education. *Science Education*, **85** (1), 6-34.