Taking IBSE into Secondary Education

Report on the conference, York, UK, October 27-29 2010

Contents

1. Introduction

2. What does inquiry-based science education mean for students and teachers?

3. Why IBSE?

4. Challenges to current practice
- 4.1 What needs to change?

5. Meeting the challenges
- 5.1 The curriculum content
  - 5.1.1 Identifying big ideas
  - 5.1.2 Transfer from primary to secondary school
- 5.2 Science Education pedagogy
  - 5.2.1 IBSE pedagogy
  - 5.2.2 Practical work
  - 5.2.3. New technologies and IBSE
- 5.3 Relevance of the content as seen by students
- 5.4 Curriculum organisation
  - 5.4.1 Teachers' knowledge
  - 5.4.2 Scheduling IBSE
- 5.5 Assessment and testing
  - 5.5.1 Formative assessment
  - 5.5.2 Summative assessment

6. Conclusions and recommendations
- 6.1 Conclusions
- 6.2 Recommendations

References

Appendices
- A Conference programme
- B Participants (delegate contact details)

Website (https://www.wellcometrustevents.org/ibse)
- Poster abstracts and Plenary presentations

1. Introduction

This conference was convened to discuss the many issues involved in beginning or extending the use of Inquiry-Based Science Education (IBSE) in the secondary school. In many countries IBSE is being implemented in a proportion of primary schools (schools for children up to the age of 11/12). In some cases this has resulted from projects initiated through the IAP science education programme which has been promoting inquiry-based teaching and learning in primary schools since 2004. Other initiatives pre-dated the IAP programme and have provided materials, training and experience to support developments in other countries. One of the reasons for extending IBSE into secondary schools is to provide some continuity in the experience of students as they move through school. There are many other good reasons for this extension, however, which were expounded in the conference. Equally there are many challenges to be met in making the necessary changes in secondary school science practice. These were well articulated in the conference and evident in the brief accounts of the situation and of on-going work in 12 of the38 countries represented at the conference, which are to be found on the conference website (https://www.wellcometrustevents.org/ibse).

In preparation for the conference a background paper was produced, informed by a Eurolatinamerican workshop held in Santiago, Chile, in January 2010. This report builds on the background paper and begins in the same way, making clear what is meant by IBSE and why it is important that it is implemented in secondary as well as in primary schools. It then considers what changes may be needed in secondary science education if all students are to have the benefits of learning through inquiry, the challenges in making these changes and how these challenges can begin to be addressed. The final section presents the conclusions and recommendations agreed by the conference participants.

2. What does inquiry-based science education mean for students and teachers?

What we mean by IBSE for students can be expressed in terms of the process and outcomes of learning about the world around. It is a process of developing understanding which takes account of the way in which students learn best, that is, through their own physical and mental activity. It is based on recognition that ideas are only understood, as opposed to being superficially known, if they are constructed by students' through their own thinking about their experiences. In the classroom these experiences include direct observation and investigation of materials and phenomena, consulting information sources such as books, experts, the internet and discussion with others in which ideas are shared, explained and defended. This learning will involve the development and use of skills of observation, raising investigable questions, planning and conducting investigations, reviewing evidence in the light of what is already known, drawing conclusions and communicating and discussing results.

It is also recognised that deep learning depends on students' full engagement in experiences from which they can develop their understanding. Engagement, in turn depends on the extent to which experiences hold interest, have perceived relevance and provide enjoyment and even excitement, for students.

Teachers have a key role in this process. What teachers do is dependent not only on their skills, but also on their knowledge, dispositions, attitudes, values and interpersonal capacities. This goes beyond what is usually meant by 'teaching' and is more accurately referred to as pedagogy in its widest meaning, including both the classroom acts and the ideas and values that inform them[1].

Inquiry is not limited to the understanding of objects and phenomena that can be directly manipulated. If this were the case it would exclude using inquiry to learn about a number of phenomena which are part of students' everyday experiences and the subject of their curiosity and questions – such as the apparent changing shape of the Moon and movement of the Sun. An essential feature of inquiry is the use of evidence from observations of such phenomena in deciding the best explanation, that is, the one that best fits the data available. The explanation may be in terms of a physical or theoretical model of which the parts can be manipulated to make predictions which are then compared with observations of the phenomena. In using models it is important to preserve the connection between observations and parts of the model, recognising that students often interpret models to fit their own ideas.

Having made the point that the subject matter does not limit the use of inquiry, it is also important to recognise that school science does involve learning things which have to be known about rather than understood. Manipulative skills of using equipment and measuring instruments, conventions, symbols and names, require direct instruction. The important point is to ensure that this knowledge facilitates inquiry and does not replace it. It is essential to use inquiry where the aim is to develop understanding.

3. Why IBSE?

The case in favour of IBSE becomes clear from considering what we want to achieve through science education. In order to prepare students for the demands of twenty-first century life it is widely accepted[2] that science education should enable students to develop key science concepts (big ideas) which enable them to understand the events and phenomena of relevance in their current and future lives. Students should also develop understanding of how science ideas and knowledge are obtained and the skills and attitudes involved in seeking and using evidence. Science education, together with students' education in other disciplines, should develop awareness of what it means to learn and the desire to continue learning, as is essential in our rapidly changing world.

In summary, through their science education students should develop:

- understanding of fundamental scientific ideas
- understanding of the nature of science, scientific inquiry, reasoning
- scientific capabilities of gathering and using evidence
- scientific attitudes, both attitudes within science and towards science
- skills that support learning throughout life

[1] Alexander, R.(Ed) 2010, p280
[2] OECD 2003, p132; Harlen (Ed) 2010

- ability to communicate using appropriate language and representations, including written, oral and mathematical language.

An inquiry approach to science education is widely advocated as being capable, if well implemented, of achieving these aims to a far greater degree than traditional approaches. The position is summed up by Alberts (2009):

> *We believe passionately in the power of science to create a better world, as well as in the critical importance for everyone in society of the values and attitudes that science demands of scientists: honesty, a reliance on evidence and logic to make judgments, a willingness to explore new ideas, and a skeptical attitude toward simple answers to complex problems. But very little of this is conveyed to students in our teaching (Alberts 2009).*

Many of the reasons for implementing IBSE in the primary school, the focus of the first five years of the IAP science education programme, also apply to secondary schools science. One reason follows from experience and research showing that the development of scientific ideas, skills and attitudes begins in the earliest years and is well advanced by the time students leave primary school. During the primary years children are forming ideas about the natural world whether or not they are taught science at school. Without experiences to guide the formation of these ideas, children form their own ideas which are often in conflict with scientific ones. The longer these non-scientific ideas are left unchallenged, the harder it is for children to change them, even in the light of conflicting evidence. So it is essential to ensure that young children are able to develop the skills and habits needed to test ideas and use them to create better understanding of events and phenomena in the world around. Moreover they enjoy investigating and finding things out and such experiences can be the basis of positive attitudes towards science. The success of implementing IBSE in primary schools has been borne out by both formal evaluation[3] and informal reports.

Similarly older students also have pre-existing ideas[4] about how scientific phenomena are explained and about the processes of scientific inquiry. Experiences which enable them to adopt more scientific ideas than their naïve theories must take account of how learning with understanding takes place. IBSE involves students working in a way similar to that of scientists, developing their understanding and challenging their preconceptions by collecting and using evidence to test ways of explaining the phenomena they are studying. This has the promise of fostering positive attitudes towards science, making it real and exciting and creating the emotional response that focuses interest and attention[5]. It also includes reflection on what has been learned so that new ideas are seen to be developed from earlier ones and the process of learning is made explicit.

A further reason relates to continuity in the experiences of science as students enter secondary education. Those who have learned science through inquiry would be disappointed to find that they have to learn in a very different way. The reaction of many is likely to be disengagement, a reduction of effort and development of a more negative attitude to science and even to school. Continuity in

3 Evaluation of the ECBI program in Chile
4 Driver et al (Eds) 1985; Black and Lucas (Eds) 1993
5 McCrory, P. 2011

all aspects is not necessarily the aim, as we see later, since young people like the stimulation of change, enjoy new challenges and want to be treated as more mature. But this desirable discontinuity should not be at the expense of progression in learning or finding that science education is an entirely different activity from their earlier experiences.

4. Challenges to current practice

The way of learning that is captured in the notion of IBSE is in considerable contrast with what is often found in secondary school science lessons. For instance, research in 2007 conducted in the UK[6], where laboratory work is considered to be more common than in many countries, reported that students found science boring, largely because, although they prefer to work in groups[7], they mostly experience whole-class teaching. One reason for this – lack of equipment – indicates a narrow view of inquiry, for productive inquiry work need not always involve equipment, but can engage groups of students in considering alternative ways of explaining events, planning investigations, or working out how to interpret data from others' experiments[8].

Even when practical work does take place it often involves all groups doing the same things, following precise instructions. This gives some relief from whole class listening but does not add greatly to conceptual understanding. The National Research Council review of high school practical work[9] found that it was not playing the part in science education that was intended. For example, in New York State, where laboratory work is required, it was included only because of the possibility of laboratory reports being inspected. Research showing that undertaking practical work at school does not correlate with performance in university physical science courses[10] is a disincentive to including it in secondary school courses. The role of practical work is considered further in discussing pedagogy (p10).

Research into students' liking for science as compared with other school subjects is given greater significance by the current recognition of the relevance of emotional response in learning.[11] According to survey results reported by Dillon[12] at the conference, agreeing that interesting things are learned in science and that science is useful does not lead to liking it as compared with other subjects or to wanting to become a scientist. The students in this survey were at the end of primary school and in early secondary school (ages 10 to 14) but were already looking away from science in terms of their future activity.[13]

---

[6] Galton and MacBeath 2008
[7] Pell et al 2007
[8] For example, Crawford, 2002
[9] NRC 2005
[10] Sadler, P and Tai, R. 2001
[11] Presentation by Wei Yu
[12] Dillon, J Presentation introduction to Theme 2
[13] The Science Aspirations and Career Choice: Age 10 - 14 project. A five year longitudinal study, funded by the Economic and Social Research Council (ESRC) as part of their Science and Mathematics Education Targeted Initiative. This project is based at King's College London

Classroom observations suggest that the teaching experienced by the students expressing boredom was characterised by few open-ended questions, little discussion of ideas and general lack of intellectual challenge. Reasons given by teachers for teaching in this way were: the overloaded curriculum, which meant that they did not feel there to be time for in-depth treatment of ideas; the 'tyranny of testing'; and in some cases lack of expertise in particular sciences, usually physics and chemistry.

IBSE holds out the promise of engaging students more productively, of giving them opportunity to enjoy science and find it rewarding. Implementation of IBSE in primary schools has resulted in science being the most-liked subject,[14] whilst in many secondary schools it quickly becomes one of the least liked.[15]

4.1 What needs to change?

Science education has the potential to serve the needs of individuals and of society. As noted in an earlier report of the IAP science education project,[16] a basic grasp of key ideas in science and about science enables learners as individuals to understand aspects of the world around them. Not only does this serve to satisfy and to stimulate curiosity but helps in their personal decisions relating to their health, their interaction with the natural environment and their choice of career. Benefits to society follow from individuals and groups making more informed choices about, for example, use of energy and resources and actions that affect their and others' wellbeing. It is clearly important for all students to gain this understanding, not just the minority who will continue study to become scientists, technologists and engineers.

Research shows that science education in secondary schools, as currently widely practised, fails in a number of ways to enable these benefits to be realised. At the same time, as noted earlier, there is wide support for the view that they can be achieved through an inquiry-based approach to teaching and learning science.[17] However, implementation of IBSE will require some fundamental changes particularly in:

The curriculum content
Science education pedagogy
The relevance of content to students' interests and everyday lives
Curriculum organisation and scheduling
The form and use of assessment and testing.

These are all interconnected and in combination amount to a change in the culture within schools. Indeed, in a presentation at the conference, Shuler[18] described the change needed as a 'change in social norms analogous to many health issues that require long-term and complex strategies'. Making a similar point, Rowell pointed out that such change could not take place without a better

[14] Allende, J. 2008
[15] Hargreaves, L. and Galton, M. 2002; Galton, M. et al 2003
[16] Harlen, W. and Allende, J. 2009 p12
[17] EC, The Rocard Report 2007; Carnegie and Institute for Advanced Study 2010; Duschl et al (Eds) 2007
18 Presentation by Sally Goetz Shuler Best Practices: Creating a Road Map for Transforming and Sustaining Model Secondary Science Education Programs.

and more widespread understanding of how IBSE is characterised and how it links to the achievement of the ideas, skills and attitudes that we want students to develop. In other words, change must go beyond what individual teachers, departments and schools can do. Action to meet these challenges is also needed by the authorities responsible for the curriculum and assessment.

We now look at these challenges in more detail and report insights from the conference on how to meet them.

5. Meeting the challenges

5.1 The curriculum content

The content is one of several aspects of the school curriculum perceived by teachers as limiting their opportunities to use an inquiry-based approach. Others, considered later, are the form in which it is expressed and how science lessons are organised in the school timetable. The content is often criticised for being overloaded, containing too many apparently unconnected items to be taught; lacking horizontal coherence and vertical continuity. The inclusion of each item might well be justified in some way but there is no obvious overall idea to which they are linked and there is no evident progression. The overload is often compounded by the content being expressed as a number of items 'to be taught', indicating a transmission approach to teaching and dictating the study of topics without regard to relevance to students. As a result, many students feel that they are being 'frog-marched' across the scientific landscape[19] and experience a lack of control over their learning. Not only do teachers feel pressure to 'cover the content' but find no incentive to focus on developing inquiry skills in their students.

5.1.1 **Identifying big ideas**

Conference participants were unanimous in calling not just for a reduction in the curriculum content but less focus on learning names, terms and facts and more on understanding key ideas in depth. There was widespread support for the view that what is needed to enable IBSE implementation is a curriculum that is expressed in terms of a relatively few key, or 'big', ideas. These are ideas that are built up through study of specific phenomena appropriate to students at different points in development and which can be seen by teachers, and increasingly by students as they mature, to be related to the key overall ideas. As well as identifying these key explanatory frameworks, the curriculum should also include ideas about the nature of scientific activity and knowledge. There are various statements of such ideas. One example,[20] provided to conference participants, proposes that the curriculum should enable students to understand that:

- All material in the Universe is made of very small particles
- Objects can affect other objects at a distance
- Changing the movement of an object requires a net force to be acting on it
- The total amount of energy in the Universe is always the same but energy can be transformed when things change or are made to happen
- The composition of the Earth and its atmosphere and the processes occurring within them regulate the Earth's climate

19 Osborne, J. and Collins, S. 2001 p450
20 Harlen, W. (Ed) 2010

- The solar system is a very small part of one of millions of galaxies in the Universe
- Organisms are organised on a cellular basis
- Organisms require a supply of energy and materials for which they are often dependent on other organisms
- Genetic information is passed down from one generation of organisms to another
- Evolution is responsible for the diversity of all organisms, living and extinct.

In addition, there are ideas about the nature of scientific knowledge, how it is created and how it is used, that also form part of the key ideas that students need to understand, for instance, that:

- Science assumes that for every effect there is a cause, or multiple causes.
- Scientific explanations, theories and models are those that best fit the facts known at a particular time
- The knowledge produced by science is used in technologies to create products to serve human ends
- Applications of science often have ethical, social, economic and political implications.

Of course these ideas cannot be taught as such. They need to be developed progressively from smaller ideas derived from specific activities. Problems of over-prescription arise when they are specified in terms of a plethora of facts and terms to be learned. Then there is danger of links to the overall ideas being lost, leaving a fragmented curriculum which is well described by Alberts as 'an inch deep and a mile wide' [21]. The links can more easily be retained and reinforced by expressing the curriculum in terms of interconnected ideas, as suggested by Millar and Osborne[22] and represented in the Big Ideas report cited above. A curriculum set out in such terms would allow teachers freedom to help students develop their understanding through studying topics and problems of relevance to students.

5.1.2 Transfer from primary to secondary school

The aim is for the big ideas to develop progressively as students move through their school lives in primary and secondary school. Through a process of inquiry and sharing with others, the ideas that students have about the world around should progress from the 'small' ideas – about particular events and objects – to become 'bigger' ones which explain a range of phenomena. At various points in the course of schooling, however, there are moves for students from class to class and school to school which can interrupt this progress. The move from primary to secondary school frequently means a discontinuity in ways of learning which can negatively affect performance and attitude in relation to science[23].

Students move from primary to secondary education at a time when most are in early adolescence when maturation of the body and brain[24] brings physical, emotional, cognitive and social changes. When these coincide with change in school – moving from what is generally a small school, where classes stay together in the charge of one teacher, to a large school with separate subjects taught by

---

[21] Alberts, B. 2009
[22] Millar, R. and Osborne, J Eds 1998
[23] Royal Society 2010
[24] OECD 2007

different teachers – the impact on students can be unsettling. Friendship groups may be broken as primary children move to different schools or are placed in different classes in the 'big' school. There will also be greater emphasis on performance and taking responsibility for meeting expected standards.

The effect of this cocktail of changes has been blamed for the dip in both performance and attitudes towards school subjects that has been well documented over many years in many countries. Researchers in England[25] estimated that around 40% of pupils failed to make the expected progress in the year after transfer from primary to secondary school and for some there are significant losses. Such findings are also reported from many western countries. In relation to attitudes, studies carried out in England[26] show that boys' attitudes to science dropped significantly after the transfer to secondary school and continued to drop during the first year after transfer. The same pattern was found for girls but starting from a lower level. In subsequent years attitudes to science continued to decline but notably less so when learning through practical activities.[27]

Other reasons for the decline in achievement and attitudes have pointed to lack of communication between teachers in primary and secondary schools, when the latter are unaware of, or ignore, what the children have learned in primary school. Thus there is often repetition of work already done, disappointing the eager new students who expected science to be exciting and novel.

Actions of various kinds have been taken to smooth the experience at transfer in the hope of reducing the dip in attainment and attitudes. These actions are usefully divided into 'pastoral' and 'academic'. Pastoral actions include meetings with parents, visits of pupils to their transfer schools, visits of teachers from transfer schools to primary schools and 'buddying' arrangements for pupils in their new schools. More emphasis on academic actions in recent years has brought meetings of teachers from primary and secondary schools and sometimes teacher exchanges, post-transfer induction programmes, and 'bridging units'. Bridging units in science are ideally produced by primary and secondary teachers working together to plan units of work which are started in the primary school and continued after transfer to the secondary school. They have been evaluated with positive results but also with warnings that they be can viewed by both teachers and students as holding up engagement with the 'proper' science. It appears that many students look forward to new work in a new environment. This is not an argument for an abrupt change but to suggest that an element of discontinuity that marks passages from childhood to early adolescence[28] is not necessarily a problem and can be part of a 'careful management of change'.[29]

Experience of implementing IBSE in primary schools underlined the importance of enlisting the support of parents and the local community. Given that the IBSE approach may be very different from that experienced by the students' parents in their education and conflicts in some ways with the popular view of what learning science means, communicating reasons for making changes and

[25] Galton et al 1999
[26] Galton 2009
[27] Barmby et al 2008
[28] Measor and Woods 1984
[29] Royal Society 2010

explaining how the goals of science education will be met is important in implementing IBSE in secondary schools. As adolescents commonly become more distant from their parents this communication is even more important at secondary than at primary level.

5.2 Science education pedagogy

5.2.1 IBSE pedagogy

Some conference participants asserted that pedagogy is more important than content in enlisting interest and motivating learning. The teaching approach certainly has a central role in providing what students consider to be relevant learning experiences. Learners rarely find something interesting if they do not understand it. Thus teaching for understanding – the aim of inquiry-based education – requires attention to the plea of students for greater relevance. In IBSE students work in groups, use their own ideas but have to support them with evidence and argument, develop their vocabulary and apply their learning. In secondary schools these activities should be implemented in ways that respect students as young adults and give them some control over their learning.

The IAP science programme has developed over the five years of its activities a list of things that teachers have to do to enable students to learn through inquiry:

- ask questions that require reasoning, explanations and reflection, and show interest in the students' answers
- provide opportunities for students to encounter materials and phenomena to explore or investigate at first hand
- arrange for discussion of procedures and outcomes as well as practical investigations in small groups
- encourage, through example, tolerance, mutual respect and objectivity in small group and whole class discussion
- provide access to alternative procedures and ideas through discussion, reference to books, resources such as the Internet and other sources of help
- set challenging tasks whilst providing support (scaffolding) so that students can experience operating at a more advanced level
- encourage students through comment and questioning to check that their ideas are consistent with the evidence available
- help students to record their observations and other information in ways that support systematic working and review, including the use of conventional representations and appropriate vocabulary
- encourage critical reflection on how they have learned and how this can be applied in future learning.

Behind these statements are implicit judgements that these are valuable actions that lead to valuable learning. In other words, they refer to pedagogy, taken in its broadest meaning as including values and justifications for teaching actions. Teachers are more likely to do the things listed here if they are convinced of the value of students having first-hand experience of investigating and observing phenomena, working collaboratively in groups, talking and arguing, and so on. Thus teachers who currently teach predominantly by following a text book, whole class working and emphasising knowledge of facts, will be faced with making some considerable change in their view of what teaching means as well as in classroom techniques if they are to implement IBSE.

The pedagogical content of initial teacher education and professional development has to do more than help teachers with the techniques of questioning, managing practical work, holding group and whole class discussions, etc. It should also convince teachers of the value of these techniques, which is best done through personal experience. Teachers and trainees need to have opportunity to experience for themselves the value of questioning and trying to answer questions through inquiry.[30] The hope that teachers are more likely to convey a view of science as inquiry if they have taken part in genuine scientific research for themselves is behind professional development programmes which provide research experience for teachers. Evaluation of the impact of such programmes is, however, mixed, with those having initially better understanding of teaching and learning benefiting most.[31]It is not enough to provide experience of inquiry. It is also necessary for teachers to reflect on the experience and how it is to be shared with students.

5.2.2 Practical work

Practical work in a laboratory or classroom is assumed in many countries to have an important role in science education. But it does not always meet expectations. At the conference, Millar defined practical work as 'any science teaching and learning activity in which the students observe and/or handle the objects or materials they are studying' and identified its function, in theory, as being to link 'hands on' to 'minds on'. Teachers take it for granted that practical work has value, but researchers have found that 'as practised in many countries it is ill-conceived, confused and unproductive'[32]. A review of research[33] reported that practical work had little impact on students' understanding. In relation to practical skills, the research indicates that students are better at using equipment and carrying out practical procedures if they have had opportunities to practice doing these, rather than just being shown how to do them. However, findings concerned with inquiry skills were inconsistent. Millar identified different types of effectiveness of practical work and described an instrument for analysis of particular practical activities that can be used to improve effectiveness. He concluded that teachers should make sure that there are a few well defined objectives for practical activities: that students are thinking about what they are doing, why they are doing it and not just following instructions, or routines, and that the links between theory and what is observed are explicitly discussed.

However, there are many changes needed beyond those within the classrooms of individual teachers if IBSE is to be implemented in a school. Even if they value inquiry-based teaching, individual teachers can feel powerless in the face of obstacles created by the content and the

[30] Harlen and Allende (Eds) 2009
[31] Blanchard et al 2009
[32] Hodson, D. 1991
[33] Millar, R. 2010

scheduling of the school curriculum and by the nature of the tests and examinations they must help their students to pass. We return to these matters later.

5.2.3 New technologies and IBSE

The impact of new technologies on science education pedagogy was touched upon briefly in the conference. It was acknowledged that the use of technologies has dramatically changed the way in which students can capture evidence, find information from secondary sources, and display findings. It enables them to access museum collections from the classroom; it allows them to collect more data than before, over a longer timescale, through automated devices. It gives opportunities to communicate and exchange data with other students and scientists across the world. These things can take place in any science lesson. The question is whether or not these technologies can enhance learning through inquiry.

There is no doubt that ICTs can enrich students' experience, but what matters in learning is what sense students are making of these experiences; whether they can form effective links between new information and ideas or be used in testing models developed by the students. Thus in addition to using ICT for making better measurements and observations and extending access to other information, it is its role in supporting learning through inquiry that needs to be developed. It is also important to bear in mind that:

- Computer simulations can be useful in relation to dangerous or inaccessible processes or events, but can never replace real laboratory activity and field work. The direct observation of things in the natural world remains essential to science.
- Communication through the written word via computers or mobile 'phones cannot replace the direct sharing of experience and ideas through talk, discussion and argumentation. The immediacy of talk has a different role in learning than asynchronous communication through computers.

This last point was reinforced in the conference by frequent reference to the value of students working in groups and forming their ideas collaboratively. If they work only alone they are missing an important contribution to their understanding from fellow students. This point was illustrated by the experience of a mathematics professor at a US university[34] who noted that his African-American students were consistently performing at a lower level than comparable Chinese students. He tested various hypotheses about the causes, such as family support, motivation, income and preparation and, finding no support for them, he studied their study habits. He observed that the African-American students studied by themselves while the Chinese students spent at least a third of their study time discussing their work in groups. He helped the African-American students to study in groups and after a period of time their results of improved to a level comparable with the Chinese students.

Thus it is important that arrangements for study, whether or not assisted by computers, avoid isolating learners from each other. The aim to produce life-long learners, who understand what is

[34] Treisman 1992

involved in learning, should be seen as the development of *autonomy* rather than *independence* in learning.

5.3 Relevance of the content as seen by students

Absence of relevance is a common complaint of students about their science lessons and a reason for lack of desire to continue studying science beyond school. What is seen as relevant by teachers and other adults may not be perceived as such by young people. Relevance can have various meanings in this context. It may mean 'surface' interest, or that curiosity is aroused, or that there is evident application beyond the classroom. There is a difference between relevance of the subject matter of a topic, on one hand, and the skills and understanding being developed, on the other. The latter may not be taken into account by learners in judging relevance. What students perceive as what they are learning – and whether they see it as worth learning – will be influenced by the topic and context in which the skills and knowledge to be developed are embedded. For instance, finding the density of an object by weighing it in air and then in water may not be seen as engaging in itself, but may become so in the context of the story of the life of Archimedes of Syracuse or set as a problem to solve in the investigation of fake coins.

Relevance can also mean 'real' in the sense of being part of life. Visits to work places, such as factories, laboratories, farms and recycling plants, where science and technology are used enable students to see the applications of science in producing the food, medicines, clothes, utensils and equipment that we use in everyday life. Similarly, field studies in the natural environment provide experiences which give studies of habitats, climate and interdependence a meaning in real terms. Conference participants also mentioned summer camps and the role that scientists can have in making the link between school science content and real life. Visits or on-line discussion with scientists or technologists working in various fields, such as communications, food or sport, can help students to recognise why they need to understand key ideas. It is particularly useful for students to hear about the application of science in topics which they do not normally consider to involve science.

The interests of adolescents are different in many ways from the interests of primary school pupils. They are also mixed and contradictory, influenced by the physical, emotional, neurological and social changes taking place at puberty. So, their interests will be very much centred on themselves, on their appearance, diet, sport, music and their relationships with their peers. At the same time, their developing ability for abstract thinking and their rapid cognitive development bring interest in local and global environmental issues, such as conserving energy, recycling, and protecting endangered species. These developments provide challenges but also opportunities for curriculum developers and teachers to use contexts that motivate engagement in learning science.

This was one of several occasions during the conference where the potential role of academies of science and academicians was mentioned. Experts have the power to enthuse students and their broad vision of their subject enables them to express complex ideas in simple terms and through analogies. They are a valuable resource for students and teachers.

5.4 Curriculum organisation

An obvious feature of the topics that interest young people is that they involve several science disciplines. This is not surprising since real life, the key reference in this context, is complex and requires interdisciplinary study. The conference presentation by Wei Yu[35] distinguished between multidisciplinary and interdisciplinary study. In many countries students study the main science disciplines throughout compulsory schooling. How this is organised varies considerably; it may be through separate study of biology, physics and chemistry, sequentially or in parallel, or through an integrated approach combining all three. Separate study is least likely to provide opportunity for students to bring together their learning in the different science disciplines. However, even within a supposedly integrated approach there is often more separation of topics into biology, physics and chemistry than the title suggests. Interdisciplinary study, by contrast, requires the application of knowledge and understanding of more than one discipline in another. However, it presents a problem for teachers who, though trained in one science, find themselves needing expertise in others.

5.4.1 Teachers' knowledge

Fear that group and class discussions could take them beyond the comfort zone of their subject knowledge can affect teachers' pedagogy and limit students' opportunities for sharing and defending their ideas. Need for expertise across the sciences, as is likely to be required for topics that particularly engage students – such as relating to forensic science, sport science, music mixing and recording – may deter some teachers from giving students opportunities for extended investigations. As in the case of primary teachers,[36] those who lack confidence in their subject knowledge tend to use teaching methods that confine students' activities to ones that are 'safe' and often impoverish students' learning opportunities, relying heavily on a text book, emphasising expository teaching, underplaying questioning and discussion, and avoiding using any equipment that might 'go wrong'.

It is unrealistic to expect teachers to have expertise across all science disciplines, but it should be possible for them to have access to help where they need it. Perhaps the most immediate means of providing this is through science teachers working in teams (as illustrated in the presentation by Goodrum), contributing their particular knowledge in planning topics and helping with questions and problems that arise as students' work progresses. Teamwork has value in itself in counteracting the isolation teachers often feel. The mutual support among members of a team also helps in relation to finding solutions to problems that may arise in using as inquiry-based approach. Again, conference participants noted a role for science academies in supporting teachers' confidence in work which is outside their area of expertise.

5.4.2 Scheduling IBSE

The freedom to use methods of inquiry is partly controlled by the time available for science and how that time is scheduled. The organisation of the school timetable presents an obstacle when, as is often the case, it provides no extended periods where students can study topics in depth or engage

[35] Conference presentation by Wei Yu
[36] Referred to in Harlen and Allende 2009

in problem-finding, problem-solving and reflection. A series of short lessons may suit methods aimed at memorisation, but not inquiry-based teaching. What is needed – and it should not be too difficult to arrange given the will – is for science to be scheduled in 2 or 3 consecutive lesson, allowing the teacher to use this time for extended inquiries on a regular basis. Arrangements of this kind were described in her conference presentation by Shuler as an example of best practice in secondary science education. In a school for science and technology in Virginia, the class schedule for four days of the week was divided not into the usual eight periods of 45 minutes a day, but only into four periods of 90 minutes.

This may not be feasible in schools which do not focus on science and technology but since there are other subjects which could benefit from longer blocks of time it ought to be possible to arrange for all students to have opportunities for sustained inquiries on sevejral occasions during the school year. For instance, the timetable could be suspended for several days each half semester, to allow students, in groups supported by teams of teachers, to work on long-term projects that can be continued if appropriate throughout the year. The experience of teamwork among students is itself an important feature of learning about the nature of scientific activity and longer periods of time enable them to become more engaged, creative and reflective in their activities.

5.5 Assessment and testing

Among the several factors that can influence teaching methods, by far the greatest influence comes from the forms of student assessment that are used. All assessment will influence what is taught and how it is taught to some extent. Indeed this is one of the intentions of formative assessment and why it has a key role in helping learning, providing feedback to the teacher and student to inform the pace and next steps of learning.

5.5.1 Formative assessment

Formative assessment, or ‘assessment for learning’, as it is also called, engages students in their own learning through a cyclical process in which information about students’ ideas and skills informs on-going teaching. It involves the collection of evidence about learning as it takes place, the interpretation of that evidence in terms of progress towards the goals of the work, the identification of appropriate next steps and decisions about how to take them. It is an essential part of inquiry, helping to regulate teaching and learning processes to ensure progression in learning with understanding. It is also central to enabling students to acquire ownership of their learning, one of the key features of genuine understanding. Ownership requires that students know the goals of their work and the quality criteria to be applied so that they can themselves assess where they are in relation to the goals. This puts them in a position to identify, with their teachers, the next steps in their learning and to take some responsibility for progress towards the goals.

Assessment only has a formative role if the information gained is used, which means that teachers have to be prepared to adapt their teaching accordingly. Introducing formative assessment is likely to require a considerable change in pedagogy, just as in the case of inquiry-based teaching. Indeed, full implementation of inquiry involves the use of formative assessment so that information is gathered about relevant aspects of students’ learning processes and achievements. The aims of inquiry-based teaching and formative assessment also coincide in helping students to take some responsibility for their learning, requiring teachers to have the confidence to give some control to students.

Secondary teachers have less time to get to know their students than do primary teachers, although their more mature students are more readily engaged in discussing the goals and criteria for judging quality. Both primary and secondary teachers, however, need help in the form of well-tried strategies which they and their students can use. Strategies for translating the theory of formative assessment into practice have been developed by researchers working with working with teachers.[37] These strategies and other procedures suggested by conference participants include:

- providing students with ways in which they can signal whether they feel confident in understanding their work or need help (for instance, by using traffic light coloured cards or objects)
- opportunities for group discussion so that students can share and check their ideas with their peers
- students preparing oral presentations and answering questions from their peers
- examples of types of questions to stimulate students' use of inquiry skills
- teachers selecting students randomly to answer questions, rather than only those who offer to answer, thus encouraging all to think and be ready to answer
- teachers sharing with students the criteria used in analysing students' reports or note books so that they can evaluate their own work as it progresses and use the information to improve it
- teachers providing feedback, orally or in writing, that is non judgemental and indicates how the work can be improved.

5.5.2 Summative assessment

Teachers often encounter pressure to produce marks and grades on every piece of work. Marks and grades are appropriate for summative assessment but not capable of providing formative feedback. It should be recognised that summative assessment has a different role from formative assessment in students' education, as a regular but infrequent event. By checking up, summarising and reporting what has been learned it enables progress to be monitored by teachers, students, parents and others. It is no less important than formative assessment but its impact can be less positive, depending on what is assessed, how it is assessed and how the results are used. These factors are not independent of each other. For example, when the results of assessment are used for important decisions affecting the student or the teacher this influences the form and content of the assessment.

Results for individual students are used within the school for monitoring their progress, record keeping, reporting to parents, the students and other teachers, for career guidance and perhaps for grouping or setting. The results may also be used by agencies outside the school to select students for college or university or to award qualifications. These uses directly affect the individual student

[37] Black and Harrison 2004

to some degree, sometimes having the potential to influence their future learning and so having 'high stakes' for the student.

In addition to using student assessment results as information about each as an individual, the aggregated results of summative assessments for groups of students are used both within and outside the school. These uses affect students more indirectly through the decisions made about, for instance, policies, programmes and use of resources. More controversially, aggregated results may also be used by agencies and authorities outside the school for accountability, for setting targets and for evaluating teachers, schools, local or district education authorities according to whether such targets are met. This use can lead to unfairness if students' performance is the only information used in evaluating the school, regardless of other factors. Using national test results in this way and for monitoring trends in achievements over time within and across schools, districts and across a whole system is also problematic. The information from a test given to every student is limited to the sample of the subject domain that any one student can reasonably be expected to take. This sampling error reduces the validity of the tests. The validity is increased by using a larger number of items which cover the domain more thoroughly, as in surveys such as PISA and TIMSS[38] where different items are given to different samples of students.

When the results of test and examinations are used to set targets for teachers and schools this makes them 'high stakes' for the teachers even though they may not have high stakes for the students. The higher the stakes – whether for students, teachers or both – the greater is the tendency to focus teaching on what is assessed to ensure maximum success. It is also the case that high stakes means that the reliability, or accuracy, of the assessment is emphasised in the interest of fairness. This leads to a preference for formal tests and examinations, especially the forms which are described as being more 'objective' than, say, methods based on judgments of teachers, even though these may provide a more complete picture of students' attainment. Further, efforts to increase the reliability of a test mean that the sample of items included in a test will favour those items that can be most consistently marked – those requiring factual knowledge and using a closed format (multiple choice or short answer) – and the exclusion of those requiring application of knowledge and more open-ended tasks more suited to assessing understanding. Conversely, attempts to increase validity by widening the range of items, say by including more open-response items where more judgement is needed in marking, will generally mean that the reliability is reduced.

As well as teaching to the tests high stakes testing leads to students spending time practising tests. The impact on students is to promote a view of learning as product rather than process[39] and is particularly de-motivating for lower-achieving students who are constantly faced with evidence of their failure. These impacts are more serious given the narrowness of what is tested. Defining what science education means in this way 'is a great tragedy, inasmuch as it trivializes education for young people'[40].

---

[38] Harlen,2007 Chapter 9
[39] Harlen, W and Deakin Crick, R. 2003
[40] Alberts, B. 2009

For these various reasons many current tests and examinations do not give valid information about progress and attainment in relation to the aims of IBSE. It is urgent that action is taken; otherwise the assessment regime will be a constant brake on attempts to implement IBSE in secondary schools.

One course of action would be to replace at least some summative tests by moderated assessment by teachers. This has the advantage of ensuring alignment of the assessment with the curriculum aims, since teachers have access during teaching to information about the full range of skills, knowledge and understanding that are the goals of the inquiry-based curriculum. It has the further advantage of using data that teachers collect during teaching and which they can use to help learning, thus serving both formative and summative assessment purposes. However, implementing this course of action successfully would require extensive professional development, clarification of criteria and procedures for standardising and moderating teachers' judgments. Although these processes all have benefits for practice, they are part of a longer-term solution. Meanwhile a more immediate course of action would be to improve the tests and examinations being used. As was pointed out by participants the instruments used in PISA surveys provide good examples of items that assess a range of inquiry skills, critical evaluation of evidence and the application, rather than the recall, of scientific ideas and principles. A further change could be made by requiring, as part of the examination, one or more extensive inquiries carried out by students during the school year.

6. Conclusions and recommendations

In the final session of the conference participants discussed a first draft of conclusions and recommendations. After this discussion a revised list was prepared and circulated to all participants Further changes were made in the light of comments, resulting in the following list.

6.1 Conclusions

1. The consensus of the participants in this conference is that the scientific knowledge, understanding, skills and attitudes needed by all students, regardless of whether or not they will proceed to further study or employment in science-based occupations, are best developed through inquiry-based science education (IBSE) which begins in the primary school and continues throughout the compulsory years of schooling.

2. IBSE means students progressively developing key scientific ideas through learning how to investigate and build their knowledge and understanding of the world around. They use skills employed by scientists such as raising questions, collecting data, reasoning and reviewing evidence in the light of what is already known, drawing conclusions and discussing results. This learning process is all supported by an inquiry-based pedagogy, where pedagogy is taken to mean not only the act of teaching but also its underpinning justifications.

3. IBSE offers the opportunity to foster enjoyment and interest in scientific activity and increase understanding of the world, as is necessary for every individual to make informed decisions affecting their own wellbeing and that of society and the environment. Further, an inquiry-based

approach can help to reverse the decline in many countries in the number of students interested in science, which is currently threatening to endanger the general level of scientific understanding needed as society becomes increasingly dependent on the applications of science and technology.

4. Since the phenomena and questions students meet in the context of daily life cut across the disciplines of science, the experiences gained from an inquiry-based science education should reflect the interdisciplinary nature of scientific activity and the content of science.

5. Effective implementation of IBSE in the secondary school (for pupils aged 11/12 to 15/16 years) is different from, and to some extent more challenging than, implementation at the primary level on account of several constraints, in particular:
    a. overcrowded curricula, which are mainly oriented to factual knowledge;
    b. the form and nature of most summative testing, including university entrance examinations, which do not sufficiently reflect the objectives and outcomes of IBSE;
    c. the limitation of teachers' knowledge, understanding and confidence across scientific disciplines;
    d. the lack of understanding of the value of IBSE within the current tradition of secondary science education;
    e. the impact on classroom life of the physical, psychological and emotional changes taking place at adolescence.

6.2 Recommendations

6. The long-term aim of IBSE implementation implies fundamental curriculum change. But a start should be made on the identification of a limited number of key science ideas, which are relevant to the current and future life of all students, are progressively developed through primary and secondary education and link to the curriculum beyond the compulsory years. Scientists in Science Academies and universities have an important role, in collaboration with science educators and educational policy makers, in identifying these key ideas.

7. More appropriate tests and procedures should be developed for assessing the understanding and skills which are the aims of IBSE. This development should include the use of ICT and summative assessment by teachers.

8. Teacher education, both pre-service and in-service, should develop teachers' interest and confidence across scientific disciplines, the pedagogical skills required for teaching through inquiry and the skills of formative and summative assessment.

9. In order to make progress towards successful implementation of IBSE in secondary education, pilot projects should be set up, building on the expertise already developed for primary education. These pilots should:

a. provide training for teachers in interdisciplinary IBSE pedagogy and in the related skills of formative and summative assessment;
b. enable schools to explore new approaches to organising the class schedule, in order to provide appropriate time sequences and collaboration among teachers;
c. permit schools to provide alternative rigorous curriculum and assessment arrangements where current requirements would excessively constrain needed changes;
d. encourage the sharing of practices across non-science disciplines, particularly with mathematics, language and history;
e. enlist the participation of active scientists, technologists and engineers to give teachers confidence in aspects of science in which they may not have been trained;
f. develop innovative uses of ICT which retain an inquiry-based pedagogy;
g. share the intentions, processes and outcomes of IBSE with parents, the business community, industry, scientists in higher education and policy-makers.

10. In addition to the evaluation of pilot projects other research studies should be conducted to understand the factors that inhibit change in pedagogy and content in science education and how to meet the challenges these present.

References

Alberts, B. (2009) Restoring science to science education, *Issues in Science and Technology,* Summer 2009, 77-80. University of Texas at Dallas.

Alexander, R.(Ed) (2010) Children, their World, their Education. London: Routledge.

Allende, J. (2008) Editorial: Academies active in education, *Science,* 321, 1123

Barmby, P., Kind, P. and Jones, K. (2008) Examining secondary school attitudes in secondary science. *International Journal of Science Education,* 30 (8):1075–93.

Black, P. and Harrison, C. (2004) *Science Inside the Black Box*. London: GL Assessment.

Black, P. and Lucas, A. (Eds) (1993) *Children's Informal Ideas in Science.* London: Routledge.

Blanchard, M.R., Southerland, S.A, and Granger, E. M.(2009**)** No silver bullet for inquiry: Making sense of teacher change following an inquiry-based research experience for teachers, *Science Education*, 93, 322-360.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching,* 37, 916-937.

Driver, R., Guesne, E. and Tiberghien, A. (Eds) 1985. *Children's Ideas in Science.* Milton Keynes: Open University Press.

Duschl, R. A., Schweingruber, H.A. Shouse, A.W. (Eds) (2007) *Taking Science to School: Learning and Teaching Science in Grades K-8* Washington DC: The National Academies Press.

European Commission (2007) *Science Education Now: A renewed pedagogy for the future of Europe*, (The Rocard report), Brussels: EC.

Galton, M. (2009) Moving to secondary school: initial encounters and their effects. In Perspectives on Education 2 (Primary-secondary transfer in science) pp5-21. London: The Wellcome Trust.

Galton, M., Gray, J. and Rudduck, J. (1999) *The Impact of Schools Transitions and Transfers on Pupil Progress and Attainment*. Research Report RR131 London: Department for Education and Employment Publications.

Galton, M., Gray, J. and Rudduck, J. (2003) *Transfer and Transitions in the Middle years of Schools (7-14): Continuities and Discontinuities in Learning*. Research Report 443. Nottingham: Department for Education and Skills Publications.

Galton, M. and Macbeath, J. (2008) *Teachers under Pressure?* London: Sage.

Harlen, W. (2007) *Assessment of Learning*. London: Sage.

Harlen, W. (Ed) (2010) *Principles and Big Ideas of Science Education*. Hatfield: ASE.

Harlen, W. and Allende, J. (2009) *Report of the Working Group on Teacher Professional Development in Pre-Secondary IBSE.* Fundación para Estudios Biomédicos Avanzados, Facultad de Medicina, University of Chile.

Harlen, W. and Allende, J. (2006) *Report of the Working Group on International Collaboration in the Evaluation of IBSE Programs.* Fundación para Estudios Biomédicos Avanzados, Facultad de Medicina, University of Chile.

Harlen, W. and Deakin Crick, R. (2003) Testing and motivation for learning, *Assessment in Education,* 10(2)169-207.

Hargreaves, L. and Galton, M. (2002) *Moving from the Primary Classroom: 20 years on.* London: Routledge.

Hodson, D. (1991). Practical work in school science: Time for a reappraisal. *Studies in Science Education,* 19, 175-184.

Measor, L. and Woods, P. (1984) *Changing Schools: Pupils' Perspectives on Transfer to a Comprehensive.* Milton Keynes: Open University Press.

McCrory, P. (2011) Developing interest in science through emotional engagement. In W. Harlen (Ed) *ASE Guide to Primary Science Education.* Hatfield: ASE.

Millar, R. (2010). Practical work. In J. Osborne and J. Dillon (Eds.), *Good practice in science teaching: What research has to say*, 2nd edn. London: McGraw-Hill.

Millar, R. and Osborne, J. (Eds) (1998) *Beyond 2000 Science Education for the Future.* London: King's College, School of Education.

NRC (National Research Council) (2005) *America's Lab Report: Investigations in High School Science*. Washington, D.C.: National Academies Press.

OECD (2003) *The PISA 2003 Assessment Framework*. Paris: OECD.

OECD (2007) *Understanding the Brain: The Birth of a Learning Science.* Paris: OECD.

Osborne, J. and Collins, S. (2001) Attitudes towards science: a review of the literature and its implications. *International Journal of Science Education*, 25 (9), 1049-79.

Pell, T., Galton, M., Steward, S., Page, C. and Hargreaves, L. (2007) Group work at Key Stage 3: Solving an attitudinal crisis among young adolescents? *Research Papers in Education*, 22(3): 309–32.

Royal Society (2010) *Science and Mathematics Education, 5 – 14. A 'state of the nation report'*. London: The Royal Society.

Sadler, P. and Tai, R. (2001). Success in introductory college physics: The role of high school preparation. *Science Education*, *85* (111), 136.

Treisman, U. (1992) Studying students studying calculus: a look at the lives of minority mathematics students in college, *The College Mathematics Journal,* 23 (5) 362-372.

Appendix A Conference programme

WEDNESDAY 27 OCTOBER 2010

09.00 *Registration*

09.15 **Welcome and introduction to the conference and its venue**
Dr. Jorge Allende
Dr. Yvonne Baker, Director of the NSLC, UK

10.00 **Issues in taking IBSE into secondary schools (presentation of background paper):**
Chair: Dr. Jorge Allende
Dr. Wynne Harlen, UK

10.30 *Coffee break*

11.00 **Theme 1 group discussions: Issues related to IBSE pedagogy in the context of the secondary school**
Dr. Pierre Léna, France
Dr. Patricia Rowell, Canada

13.00 *Lunch*

14.15 **Theme 2 group discussions: Issues relating to making science engaging and relevant to young people as they move into secondary schools**
Dr. Hubert Dyasi, USA
Dr. Justin Dillon, UK

16.15 *Tea/Coffee break*

16.30 **Plenary presentation: Best practices in transforming and sustaining secondary science education programmes**
Chair: Dr. Ruediger Klein, ALLEA, Europe
Ms Sally Goetz Shuler, Executive Director, National Science Resources Centre, USA

17.15 **Plenary presentation: Recent research on the role of practical work in science education**
Chair: Dr. Ruediger Klein, ALLEA, Europe
Dr. Robin Millar, Salters Professor of Science Education, University of York.

18.30 *Pre-dinner drinks reception*

18.45 *Informal dinner*

20.00 **Round table of developing IBSE projects**
Chair: Dr. Jorge Allende
With contributions from:
Dr.Jackie Olang, Kenya
Dr. Arthur Eisenkraft, USA
Tahereh Rastgar, Iran
Dr. Norma Nudelman, Argentina
Dr. Michael Reiss, UK

THURSDAY 28 OCTOBER 2010

09.00 **Theme 3 group discussions: Issues relating to implementation of IBSE in secondary schools for teacher training and curriculum organization**
Dr. Alice Pedregosa, France
Dr. Derek Bell, UK

11.00 *Coffee break*

11.30 **Plenary presentation: Lessons from globalisation : PISA 2006 and 'reaching the unreached' in Kallupati, India**
Chair: Dr. José Lozano, Colombia
Dr. Roger Establé, France

12.15 **Plenary presentation: What is the impact of neuroeducation on IBSE?**
Chair: Dr. José Lozano, Colombia
Dr. Wei Yu, China

13.00 *Lunch*

14.15 **Theme 4 group discussions: Issues relating to formative assessment and summative assessment and testing in the context of IBSE**
Dr. Paul Black, UK
Dr. Rosa Deves, Chile

16.15 *Tea/Coffee break*

16.45 ***Posters and view of the NSLC and STEM centre resources**
Introduced by Dr. Mary Ratcliffe, Deputy Director of the NSLC

19.00 *Drinks reception*

19.30 *Conference Dinner*
Welcome by Dr Jane Grenville, Pro-Vice-Chancellor, University of York

*Posters and poster abstracts can be found on the website:
(https://www.wellcometrustevents.org/ibse)

FRIDAY 29 OCTOBER 2010

09.00 **Plenary presentation: Implementing IBSE: turning rhetoric into reality**
Chair: Dr. Guillermo Fernandez de la Garza, Mexico
Dr. Denis Goodrum, Australia

09.45 **Theme summaries: theme presenters**
Chair: Dr. Soon Ting Kueh, Malaysia

10.45 *Coffee break*

11.15 **Conclusions and recommendations:**
Chair: Dr. Jorge Allende
Dr. Derek. Bell
Dr. Pierre Léna
Dr. Wynne. Harlen
Participants

End of main conference

12.30 *Lunch*

14.00 **ALLEA Working Group Science Education**
(working meeting for delegates from ALLEA Member Academies only)
17.00 Close

Discussion sessions

Each session is focused on one of four themes and led by two 'presenters' who will

a) set the scene for the theme and questions for discussion (15 minutes)

b) circulate discussion groups (which meet for 1 hour)

c) lead a round table of reporters from each group and make a response (45 minutes)

+

Appendix B Participants Contact Details

Professor Maija Aksela
Finland's Science Education Centre, LUMA
B.O.X 55
Helsinki
00014 University of Helsinki
Finland
T +358-50-5141450
E maija.aksela@helsinki.fi

Professor Jorge Allende
IAP Coordinator
Independencia 1027, Santiago Chile
Facultad de Medicina Universidad de Chile
Santiago 8380453
Chile
T 56-2-978 6255 or 56-2 -978 2246
E jallende@abello.dic.uchile.cl

Professor Arvind Arvind
Indian Institute of Science Education and Research Mohali
MGSIPAP Complex, Sector 26
Chandigarh 160019
India
T +911722791024
E arvind@iisermohali.ac.in

Ms Hannah Baker
Wellcome Trust
215 Euston Road
London NW1 2BE
United Kingdom
T 020 7611 8636
E h.baker@wellcome.ac.uk

Ms Yvonne Baker
Myscience.co Limited
National Science Learning Centre
University of York
York YO10 5DD
United Kingdom
T 01904 328381 (PA)
E y.baker@slcs.ac.uk

Professor Derek Bell
Wellcome Trust
215 Euston Road
London NW1 2BE
United Kingdom
T 020 7611 8843
E d.bell@wellcome.ac.uk

Mr Bryan Berry
Science Learning Centre South West
At-Bristol
Anchor Road, Harbourside
Bristol BS1 5DB
United Kingdom
T 0117 9157104
E bryan.berry@at-bristol.org.uk

Professor Paul Black
King's College London
150 Stamford Street
London SE1 9NH
United Kingdom
T 020 7848 3166/3183
E paul.black@kcl.ac.uk

Dr Martin Braund
University of York
Science Education
Department of Educational Studies
Alcuin College 'D' Block, Heslington
York YO10 5DD
United Kingdom
T +44(0)1904 433465
E mb40@york.ac.uk

Mr William Cassidy Ill
National Science Resources Center
901 D Street, SW
Suite 704B
Washington 20024
USA
T 202.633.2972
E wdc03@earthlink.net

Professor Beno Csapo
University of Szeged
Petofi S. sgt. 30-34
Szeged
H6722
Hungary
T +36 62 544032
E csapo@edpsy.u-szeged.hu

Professor Rosa Deves
Universidad de Chile
Diagonal Paraguay 265
Santiago
Chile
T 562- 9781024
E rdeves@med.uchile.cl

Professor Justin Dillon
King's College London
Franklin-Wilkins Building
150 Stamford Street
London SE1 9NH
United Kingdom
T 07785 330536
E justin.dillon@kcl.ac.uk

Professor Stanislav Dovgyi
Minor Academy of Sciences of the Ministry of Education and Science of the National Academy of Sciences of Ukraine
3 Mishyna St., #502
Kyiv 03151
Ukraine
T +380671155112
E khilko_y@ukr.net

Professor Hubert Dyasi
Retired
48 Arthur Place
Yonkers,
NY 10701-1703
United States
T 914-963-9062
E hdyasi@aol.com

Professor Arthur Eisenkraft
University of Massachusetts Boston
100 Morrissey Boulevard
COSMIC - Wheatley 4-181
Boston 02125
United States
T 617-287-7652
E eisenkraft@att.net

Professor Roger Establet
LAMES CNRS Université de Provence
4 rue des pénitents 13840 Rognes
France
T 04 42 64 31 01
E roger.establet@gmail.com

Mr Guillermo Fernandez de la Garza
FUMEC
San Francisco 1626-205 Col Del Valle
Benito Juárez
México D.F. 03100
Mexico
T 52 55 52 00 05 60
E gfernandez@fumec.org

Dr Issaou Gado
National Institute for Teacher Training and Research
02 BP 159
Porto-Novo
Benin
T (229) 97 15 29 16
E igado@kent.edu

Mr Maksym Galchenko
Institute of Gifted Child of the National Academy of Pedagogical Sciences
11-A Saliutna St.
Kyiv 03190
Ukraine
T +380503554330
E halchenko@yahoo.com

Ms Sally Goetz Shuler
National Science Resources Center
901 D Street, SW
Suite 704B
Washington 20024
USA
T 202.633.2972
E ShulerS@si.edu

Professor Denis Goodrum
Australian Academy of Science
Ian Potter House
Gordon Street,
Canberra 2601
Australia
T 02 62019428
E denis.goodrum@science.org.au

Professor John Grue
The Norwegian Academy of Science and Letters
Drammensveien 78
Oslo NO-0271
Norway
T +4741607182
E johng@math.uio.no

Professor Wynne Harlen
Haymount Coach House
Bridgend
Duns
Berwickshire TD11 3DJ
Scotland
United Kingdom
T 01361 88710
E wynne@torphin.freeserve.co.uk

Prof Sven-Olof Holmgren
RSAS and Stockholm University
Rörstrandsgatan 10
Stockholm SE 113 40
Sweden
T +46 739 808025
E soh@fysik.su.se

Mr Mohamed Hosni
Ministère de l'éducation nationale- Centre des innovations pédagogiques et d'expérimentation
Bab Rouah- Rabat
73, Bd Moulay Ismail, Hassane, Rabat
Rabat 10000
Morocco
T 0661901468
E hosnias@gmail.com

Professor Leo Houziaux
Royal Academy of Belgium
Palace of the Academies,
1, rue Ducale
Brussels B 1000
Belgium
T +32477723994
E leo.houziaux@ulg.ac.be

Professor Haruyuki Iwabuchi
Japan Science and Technology Agency
5-3, Yonbancho,
Chiyoda-ku,
Tokyo 102-8666
Japan
T 81-3-52148993
E iwabuchi@jst.go.jp

Miss Elizabeth Jeavans
The Royal Society
6 - 9 Carlton House Terrace
London SW1Y 5AG
United Kingdom
T 020 7451 2561
E elizabeth.jeavans@royalsociety.org

Mr Stevan Jokic
Vinca Institute
Mike Petrovica Alasa 12-14
Belgrade 11001
Serbia
T +381112455041
E sjokic@vinca.rs

Professor Nikola Kallay
Croatian Academy of Sciences and Arts
Zrinski trg 11
Zagreb 10000
Croatia
T +385-1-4606133
E nkallay@chem.pmf.hr

Professor Yucel Kanpolat
Turkısh Academy of Sciences
Piyade sok. No:27
Cankaya
Ankara 06550
Turkey
T +90 312 442 41 85
E tubaulus@tuba.gov.tr

Professor Chris King
Earth Science Education Unit, Keele University
Keele
Staffordshire, ST5 5BG, UK
United Kingdom
T 01782 734437
E Chris@cjhking.plus.com

Mr John Kirkland
Association of Commonwealth Universities
Woburn House
20-24 Tavistock Square
London WC1H 9HF
United Kingdom
T 02073806700
E j.kirkland@acu.ac.uk

Dr Rudiger Klein
ALLEA
c/o KNAW
Kloveniersburgwal 29
Amsterdam 1073XC
Netherlands
T +31-20-5510-722 (secr.: -754)
E rudiger.klein@allea.org

Professor Andrej Kranjc
Slovenian Academy of Sciences and Arts
Novi trg 3
Ljubljana
SI-1000
Slovenia
T +386 1 47 06 128
E andrej.kranjc@sazu.si

Dr José Lozano
Academia Colombiana de Ciencias Exactas, Físicas y Naturales
Carrera 28 A No. 39 A - 63, Bogota, Colombia, South America
Bogotá
Colombia
T 571-2443186; 571-2683290
E jlozano@accefyn.org.co

Professor Pierre Léna
Académie des sciences, Paris
23 quai de Conti
Paris 75015
France
T 33 (0)1 44 41 45 62
E pierre.lena@obspm.fr

Professor Winston Mellowes
Caribbean Academy of Sciences
c/o Department of Chemical Engineering, Faculty of Engineering, The University of the West Indies
St. Augustine
Trinidad and Tobago
T 8686622002 Ex 2169
E wamello@yahoo.com

Professor Randolf Menzel
Berlin Brandenburgische Akademie der Wissenschaften
Tollensestr. 43 E
Berlin 14167
Germany
T +493083853930
E menzel@neurobiologie.fu-berlin.de

Professor Robin Millar
University of York
Department of Educational Studies
Heslington
York YO10 5DD
United Kingdom
T 01904433469
E rhm1@york.ac.uk

Professor Peter Mitchell
Royal Irish Academy
Academy House
Dawson Street
Dublin 2
Ireland
T +353 1 7162222
E peter.mitchell@ucd.ie

Ms Pina Moliterno
Accademia Nazionale dei Lincei

Dr Norma Nudelman
Academia Nacional De Ciencias Exactas
Avda. Alvear 1711 4° P
Buenos Aires 1014
Argentina
T 5411 4576 3355
E nudelman@qo.fcen.uba.ar

Miss Zena O'Connor
Wellcome Trust
215 Euston Road
London NW1 2BE
United Kingdom
T 02076118442
E z.oconnor@wellcome.ac.uk

Professor Meshach Ogunniyi
University of the Western Cape
Private Bag X 17
Cape Town 7535
South Africa
T +27 21 959 2040
E mogunniyi@uwc.ac.za

Ms Jackie Olang
Network of African Science Academies (NASAC)
c/o African Academy of Sciences
P. O. Box 14798
Nairobi 00800
Kenya
T +254202405150
E j.olang@aasciences.org

Dr Alice Pedregosa Delserieys
IUFM - Aix-Marseille Université
Technopole de chateau gombert - Uniméca
60 rue Joliot Curie
Marseille cedex 13
13453
France
T 0033 6 01 91 72 11
E a.pedregosa@aix-mrs.iufm.fr

Professor Miljenko Peric
Serbian Academy of Sciences and Arts
Knez Mihailova 35
Belgrade 11000
Serbia
T +381112027342
E sasa.foreigndept@sanu.ac.rs

Mr Xavier Person
La main à la pâte
1, rue Maurice Arnoux
Montrouge 92120
France
T +33 1 58 07 65 97
E xavier.person@inrp.fr

Dr Dukagjin Pupovci
Kosova Academy of Sciences and Arts
1 Emin Duraku str
Prishtina 10000
Kosovo
T +381-38-244 257/ext. 109
E dpupovci@gmail.com

Mrs Tahereh Rastegar
Iran University of Science and Technology
Narmak,Tehran
Iran
T 98-(21)77451500-5
E rastgar@iust.ac.ir

Professor Mary Ratcliffe
Myscience
National Science Learning Centre
University of York
York YO10 5DD
United Kingdom
T 01904 328391
E m.ratcliffe@slcs.ac.uk

Mrs Alison Redmore
Science Learning Centre East of England
University of Hertfordshire
Lower Hatfield Road
Bayfordbury SG13 8LD
United Kingdom
T 01992 517626
E a.m.redmore@herts.ac.uk

Professor Michael Reiss
Institute of Education, London
20 Bedford Way
London WC1H 0AL
United Kingdom
T 020 7612 6092
E m.reiss@ioe.ac.uk

Professor Silvia Romero
Mexican Academy of Sciences
Km 23.5 s/n Carr Fed Mex-Cuernavaca. Col San Andres Totoltepec México D.F. c.p.14400
Mexico City
Mexico
T (52) 55 15 39 07 54
E silroh@yahoo.com

Dr Patricia Rowell
University of Alberta
P.O.Box 2014
Ladysmith, BC
V9G 1B5
Canada
T 1-250-245-4370
E pat.rowell@ualberta.ca

Professor Elly Sabiiti
Makerere University
Uganda National Academy of Sciences
P O Box 11499,Kampala
Kampala
P O BOX 7062
Uganda
T 256 414 542277
E esabiiti@agric.mak.ac.ug

Professor Luz Samayoa
Academia de Ciencias de Guatemala, La Ciencia en la Escuela
25 calle 10-63 zona 11 Granai II
Guatemala 01011
Guatemala
T 502 52041930
E luzsamayoa@gmail.com

Professor Peter Schuster
Austrian Academy of Sciences
Dr.Ignaz Seipel Platz 2
Wien 1010
Austria
T +43 1 4277 52736
E pks@tbi.univie.ac.at

Mrs Annette Smith
Association for Science Education
College Lane
Hatfield AL10 9AA
United Kingdom
T 01707 283006
E annettesmith@ase.org.uk

Dr Ting-Kueh Soon
FASAS_AASA
127B, Jalan Amiddunin Baki
Taman Tun Dr Ismail
Kuala Lumpur
60000
Malaysia
T 603 7728 3272
E soontk@ikm.org.my

Mrs Libby Steele
The Royal Society
6-9 Carlton House Terrace
London SW1Y5AG
United Kingdom
T 02074512577
E libby.steele@royalsociety.org

Professor Leo Wee-Hin Tan
SINGAPORE NATIONAL ACADEMY OF SCIENCE
c/o Dean"s Office, Faculty of Science
National University of Singapore, 6 Science Drive 2
Singapore 117546
T +65 65165960
E leotan@nus.edu.sg

Dr Wanida Tanaprayothsak
The Institute for the Promotion of Teaching
Science and Technology (IPST)
924 Sukhumvit Rd., Klong-toei
Bangkok 10110
Thailand
T +662- 392 4021 Ext. 1407
E wtana@ipst.ac.th

Professor Puntip Timsuksai
The Science Society of Thailand Under the
Patronage of His Majesty the King
Chemistry Department, Faculty of Sciences,
Nakhon Ratchasima Rajabhat University
Nakhon Ratchasima
30000
Thailand
T (66) 817 253 624, (66) 804 803 559
E timsuksai51@gmail.com

Professor Giancarlo Vecchio
Accademia Nazionale dei Lincei
Dipartimento di Biologia e Patologia
Cellulare e Moleolare
Piazza Sannazzaro,57,Naples,Italy,80122
Naples 80131
Italy
T 0039-081-746-3324
E vecchio@unina.it

Mr Nick von Behr
The Royal Society
6-9 Carlton House Terrace
London SW1Y 5AG
United Kingdom
T 02074512571
E Nick.VonBehr@royalsociety.org

Professor Perko Vukotic
Montenegrin Academy of Sciences and Arts
Rista Stijovica 5
Podgorica 81000
Montenegro
T + 382 20 655457
E pvukotic@yahoo.com

Professor Yu Wei
MOE Academician, Chinese Academy of
Engineering
No.37 Damucang Hutong, Xidan, Beijing, P.R.C
100816
China
T 86-10-82502773
E yw.rcls@163.net

Ms Zhu Yanmei
Research Centre for Learning Science, Southeast
Universtiy
3#, Liwenzheng Building, Southeast Universtiy
Nanjing, Jiangsu,
P.R. China 210096
China
T 13327803370
E zhuyanmei2010@yahoo.com.cn

Miss Emily Yeomans
Wellcome Trust
215 Euston Road
London
NW1 2BE
United Kingdom
T 020 7611 8254
E e.yeomans@wellcome.ac.uk

Dr Janchai Yingprayoon
The Science Society of Thailand under the
Patronage of His Majesty the King
Faculty of Science, Chulalongkorn University
Bangkok 10330
Thailand
T +66-81-6412533
E janchai@loxinfo.co.th

Mrs Lanita Yusof
Curriculum Development Centre, Ministry of Education, Malaysia
Aras 4-8, Blok E9, Kompleks Kerajaan Parcel E
Pusat Pentadbiran Kerajaan Persekutuan
Putrajaya 62604
Malaysia
T +603-88842223
E lanita.yusof@moe.gov.my

Professor Jan Zima
Academy of Sciences of the Czech Republic
Kvetna 8
Brno
CZ-60306
Czech Republic
T ++420 543 422 553
E jzima@ivb.cz

Website

(https://www.wellcometrustevents.org/ibse)

Poster abstracts

Plenary presentations