'Scientists are not always right, but they do their best.' Irish children's perspectives of innovations in science teaching and learning

Colette Murphy, Mary Mullaghy and Alice D'Arcy

ABSTRACT Research globally has shown that many children lose interest in science towards the end of primary school and throughout the post-primary phase. This article explores children's experience and views in Irish schools that have adopted innovative practices that aim to empower, excite and inspire children in science. One of these focuses on explicit teaching of the nature of science, using an inquiry-based science approach. The second involves a 25-week programme whereby scientists and primary teachers co-teach 'rocket science' through games, experiments and challenges. Children's views are used to suggest some recommendations, which may help to improve their experience of science during transition from the primary to the post-primary phase.

Why is it, in spite of the fact that teaching by pouring in, learning by passive absorption, are universally condemned, that they are still so entrenched in practice? (Dewey, 1916: 6)

It is 100 years since Dewey stated that most learning in schools by children was via transmission of knowledge from teacher to pupil, and called for education to be more grounded in experience. Today, Dewey's concern is still an issue, especially for science learning. Research shows a global trend that many children lose interest in science as they reach the end of primary school and during the post-primary phase, resulting in fewer pupils studying science at senior levels. In this article, we focus on children's experiences and their views of innovations in science learning in some Irish schools during the transition period.

In Ireland, as in many other countries, there is a strong emphasis on children's voice, particularly in relation to their health, wellbeing and education. There is also a zeitgeist for science and some interesting innovations in school science, both publicly and privately funded, which are attempting to make it more exciting, inspiring and enjoyable for children. What do children think? This article will illustrate how innovations in learning and teaching science can be effective in improving science learning for children as they move from primary to post-primary schools.

Why listen to children?

Apart from children's rights to be heard and that their views should have influence on all matters affecting them (United Nations, 1989), research evidence shows that when children are afforded the appropriate conditions to express an informed view their ideas can form the basis for improved policy and practice (see United Nations (2009) for advice on engaging children in research). In addition, children interpret findings differently from adults (Murphy *et al*., 2013). For example, when shown a bar chart from research on children's favourite subjects in primary school (Figure 1), adult researchers considered that only 10% children choosing science as their favourite subject was a 'bad news' story. The child research advisers to the study (aged 10–12 years, representing final year primary and first year post-primary schooling in England and Wales), on the other hand, suggested that, although all children like science, it is not their favourite – a very different story!

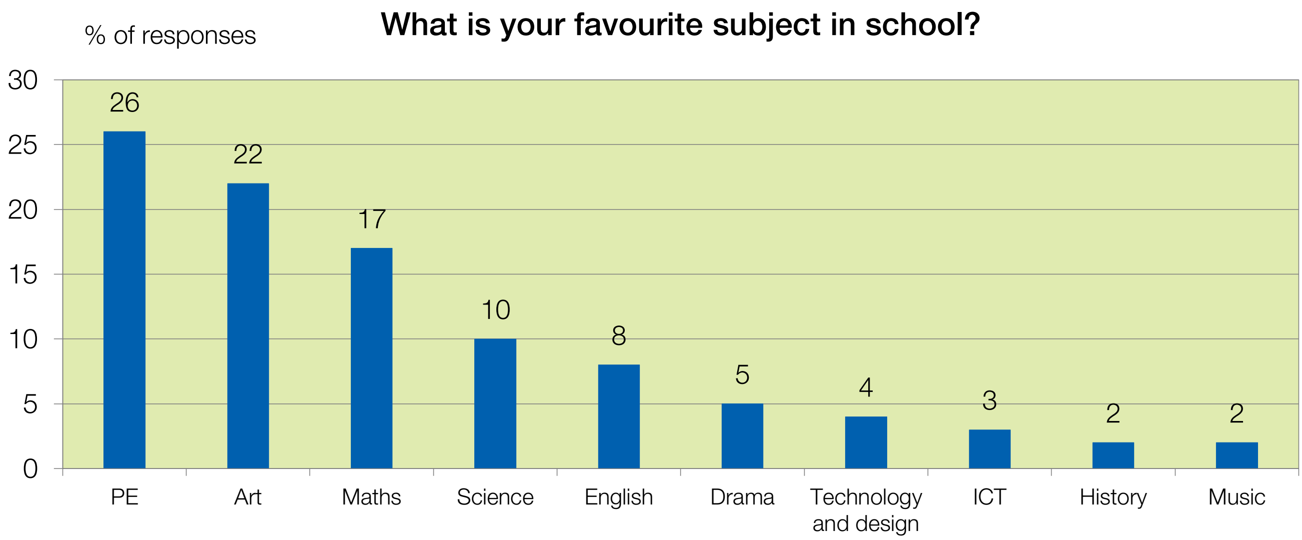

Figure 1 The children's top ten favourite subjects ($n = 891$)

Their perspective was similar to those completing the survey – an 'insider' view (Murphy *et al.*, 2013). This study also showed that children's ideas for how they might assess primary science if they were teachers mirrored some 'ideal' practices suggested by key research in primary science assessment. One child suggested:

I think I would do a group assessment to assess the children with different abilities and learning style. I would do this because I think it is unfair to some children doing well because they are more of writing answers and some children are more of talking and some are more drawing. So I would do some assessments as class work, orally asking questions to direct and by themselves. (girl, primary school)

Rather than calling for change in school science, which might be the adult interpretation of children's views, the children's reaction stimulates us to investigate ways to maintain and enhance their positive experience of science in primary school. One such approach could be to focus on children's experience of science as opposed to curriculum content and its progression, based on a distinctive primary science curriculum that takes into account what we know about how children learn, what concepts they can reasonably be expected to grasp and how science may relate to their lives outside school.

Another important reason for including children's views on science in policy and practice is to ensure that they communicate not just scientific outcomes, but also the method and process of scientific endeavour. Many science communicators do 'shows' in schools, which might provide a 'wow' effect for children, but what is also needed is a programme of work that empowers young children to think, talk and act like scientists in preparation for higher learning in science.

In Ireland, the 1998 Education Act saw the introduction of pupil councils in post-primary schools. Since then, learner voice has become more significant in the design of new curricula by the National Council for Curriculum and Assessment (NCCA) and with the inspectorate in school self-evaluation (SSE). One of the key elements of SSE is talking to pupils to get their views on learning, how they learn best and how schools can provide for that learning. Also, as part of the new Junior Cycle Reform, NCCA invited schools to participate in the Student Voice project, in order to hear about their learning experiences from participating in their own school-developed short course(s).

The context of primary/early post-primary science in Ireland

Historically, science flourished from the settlement by English and Scottish adventurers in Ireland in the 17th century intent on promoting the latest scientific and technological advances. It suffered, along with some other school subjects, from a temporary decline at the time of Irish independence in the early 20th century, due to the strong government focus on reviving the Irish language and culture. In the 1990s, however, there was a dramatic resurgence in scientific activity and interest, due, in the main part, to strong economic development. For example, eight of the top ten pharmaceutical companies in the world have Irish facilities. Consequently, school science is undergoing reform and there is strong support for early intervention to help make science a more popular subject choice for more pupils at senior levels.

The Irish primary school curriculum aims to provide a broad learning experience and encourages a rich variety of approaches to teaching and learning that cater for the different needs of individual children. The revised primary curriculum, launched in 1999, was the first complete revision of the curriculum since 1971. The revised curriculum was designed to nurture the child in all dimensions of his or her life – spiritual, moral, cognitive, emotional, imaginative, aesthetic, social and physical. The curriculum is divided into the following key areas: languages (Irish and English), mathematics, social, environment and scientific education (SESE), arts education (including visual arts, music and drama), physical education and social, personal and health education (SPHE). Science forms part of the SESE curriculum area, along with geography and history. For transition between primary and post-primary schools, the NCCA introduced the Education Passport – Report Card for the transfer of information between schools. Subject areas are rated as follows:

- experiencing significant difficulty;
- experiencing some difficulty;
- managing comfortably;
- capable and competent;
- highly capable and competent.

At second level, the education sector comprises post-primary, vocational, community and comprehensive schools. Post-primary education consists of a three-year Junior Cycle (lower post-primary), followed by a two- or three-year Senior Cycle (upper post-primary), depending on whether the optional Transition Year (TY) is taken. Pupils usually begin the Junior Cycle at age 12. The Junior Certificate examination is taken after three years. The main objective of the Junior Cycle is for pupils to complete a broad and balanced curriculum, and to develop the knowledge and skills that will enable them to proceed to Senior Cycle education.

In 2008, the NCCA in Ireland commissioned research to review the impact the primary science curriculum was having on the children's experiences of science. This report indicated a number of concerns regarding children's learning in primary science (Varley, Murphy and Veale, 2008). These included the infrequency of hands-on science and the extent to which Irish pupils were being afforded opportunities to lead their own investigations or engage in designing and making projects. The report indicated that teacher-led and prescribed activities appeared to be the norm in Irish primary classrooms. There were also concerns about the breadth and complexity of science skills being employed, in that older pupils appeared to have been operating at skill levels similar to those seen in much younger classes. The report noted, however, many similarities in the documentation relating to the science curricula at primary and post-primary (up to the end of Junior Cycle) levels in the aims, content and skills, suggesting that the documentation provides opportunities for continuity and progression across the transfer, but the reality is different. It evidenced a widespread problem of lack of confidence among primary teachers to teach science – a universal issue (Murphy *et al*., 2007; Alake-Tuenter, Biemans, Tobi and Mulder, 2013). A later report used the data from Progress in International Reading Literacy Study (PIRLS) and Trends in International Mathematics and Science Study (TIMSS) test results, and identified specific areas in which confidence was particularly low including:

answering pupils' questions about the subject, and providing suitably challenging tasks for high-performing pupils. Irish teachers' lack of confidence in these areas may be considered in light of their relatively low participation in subject-specific CPD. (Clerkin and Eivers, 2013: 101)

The reformed Junior Cycle programme is currently being rolled out in Irish schools, and the revised science specification is being taught from September 2016. It aims to consolidate efforts to progress science at primary and lower post-primary levels, and to focus on a smoother transition between primary and post-primary science. One of the most significant changes in content is that the nature of science (NoS) is now a key area in the new Junior Cycle science specification as an overarching strand, beneath which lie the four strands: biological world, physical world, chemical world and Earth and space.

Against the background of reform in Irish school science, and the focus on nature of science and inquiry-based science teaching, this article explores two key innovations designed to improve primary/post-primary science transition. The first is the explicit teaching of the NoS in primary schools, and the second is Science-in-a-Box (SIAB), a 25-week programme that supports education in science, bringing together scientists from industry and academia, primary school teachers, artists and designers to develop and deliver a coherent, innovative, engaging, curriculum-enhancing science resource to 4th–6th class pupils (age 9–12 years) in primary schools. Each innovation promotes the relevance of school science education both to the children's everyday lives and to the world of scientific wonders, as well as to the process of scientific endeavour. These innovations address the science that we do not yet know how to explain, as well as things we have learned about the world, using observation, experimentation, imagination, collaboration and perseverance.

Nature of science

The importance of teaching children about the nature of science (NoS) has been acknowledged recently in Ireland in its prominence in the revised Junior Cycle specification. In primary schools, research has been carried out over the past ten years on introducing NoS at primary level.

An initial project involved exploring the impact of explicit teaching of NoS on later primary science teaching and learning (Murphy, Murphy and Kilfeather, 2011). Part of this research focused on children's views of science, scientists and the work they do. Two groups of children completed questionnaires and were interviewed about science at the start and end of a school year. Half of these children were taught science by teachers who had themselves been taught NoS explicitly (NoS group). Teachers who had not studied the NoS course taught the other half of the sample of children (non-NoS group). Aside from this difference, both sets of teachers had completed the same 48-hour curriculum studies course in science, and both groups had similar school science backgrounds.

A good understanding of NoS is said to reveal an understanding of scientific knowledge as being testable and developmental and therefore subject to change. It appreciates science as a human activity involving subjectivity, creativity and imagination in determining scientific knowledge (Lederman and Abd-El-Khalick, 1998).

Research suggests that if pupils leave school with a good understanding of NoS they typically have a better understanding of science concepts and scientific inquiry, a greater interest in science and a better appreciation of science's role in contemporary society (McComas, Clough and Almazora, 1998). Such understandings and knowledge of science could lead to pupils finding science more interesting, comprehensible and relevant to their everyday lives. There is not much evidence to date of addressing NoS to a great extent in primary schools. The NoS project described above aimed to give primary pupils the opportunity to engage in and reflect on hands-on activities that explicitly address NoS issues.

Children who were taught by teachers who had studied NoS indeed showed a different understanding of science from those in the non-NoS group. For example, when talking about their experience of science, children in the NoS group tended to give much fuller descriptions – almost stories – of what they actually did, as opposed to those in the non-NoS group who mentioned only the types of activities they did:

We had to make a switch for a circuit … and me and C. and V. did a brilliant job. C. had this metal … and there was a metal bar, kind of like a right angle, and we had this swirly thingy, we swirled it up and we sellotaped all the wire on to the top of it, so when we turned it up to the top, the metal piece touched it, which lit the entire surface … so we had to use our imagination to make the switch. (boy, 8 years, NoS)

You learn different activities and you learn how to turn on a bulb or a battery and stuff like that… We learn how air can blow up a balloon … (boy, 9 years, non-NoS)

NoS children also evidenced a richer understanding of science in that they appreciated the role of scientists as evidence gatherers who sometimes make guesses and who are not always correct. This more critical view enables children to identify more closely with the work of scientists and to persevere in their own school science investigations if things don't work out for them the first time. Such opportunities also facilitate the application and development of scientific skills and enable children to engage with scientific concepts and issues that are relevant both to the process of science itself and to their everyday lives. In doing so pupils are facilitated in making sense of primary science. Murphy *et al*. (2011) provide examples of NoS children's allusions to some of the major tenets of NoS (science is tentative and developmental; it proceeds via inquiry; it is subjective and creative; and it builds on its history). Of these tenets, the non-NoS group responded only to prompts about science as inquiry. Examples of comments are:

I have an example of figuring out things … teacher gave us a little tiny piece of a picture and you had to figure out what it came from … [it was working like scientists because] *scientists have to guess from the stuff* [evidence] *they have and we only had, they only have a small piece, and we only had a small piece and we had to guess what* [the rest]. (girl, 8 years, NoS group – science as inquiry, science as subjective)

you get to do experiments and you find out stuff that you didn't actually know before. (girl, 9 years, non-NoS group – science as inquiry)

Scientists discover things and sometimes they make guesses. They are not always right but they do their best. (boy, 8 years, NoS group – science as subjective and creative)

The seminal work of Lev Semenovich Vygotsky (1896–1934) in foregrounding the importance of the 'social' as opposed to just the 'individual' in meaning-making and learning suggests that everything children learn at school, especially in science, should make sense to them. Indeed, Vygotsky schools in Russia build children's learning around their sense-making, by building sense frames, based around four 'super concepts' that encompass all human activity in the world. These concepts are: space (place), time, substance (materials) and human reflection (Murphy, 2015). It was interesting that most comments from the NoS group used the first person plural 'we', whereas the non-NoS children mostly used the second person 'you' in their responses. Children in the study who engaged in and reflected on NoS activities expressed a view of science that made more sense to them than children who did not do such activities.

This work supports the idea that primary school science needs to be relevant both in terms of children's everyday scientific experience and in terms of the world of science. As stated earlier, the latter aspect of relevance has received very little attention in discussions of the relevance of primary science. How else then can we enable young children to construct their world? How can we provide answers to their many 'why' questions? It seems, from our evidence, that NoS activities can help to provide this missing link. NoS activities could provide an excellent tool, or method, to support transition in science between primary and post-primary schools. The revised Junior Cycle curriculum in Ireland, to be taught from September 2016, is centred around NoS, and the current work on revisions for the primary science curriculum (NCCA, 1999) embraces the importance of NoS, so the structure is available to facilitate the use of NoS as such a support to improve the experience of science learning for children in the transition stages.

Science-in-a-Box

Science-in-a-Box (SIAB) is a privately funded project run by STEAM Education Ltd (www.steam-ed.ie) which facilitates primary children's active involvement in a holistic experience of science via a 25-week programme co-taught by scientists and their own teachers. The funding comes directly from industry and aims to address a critical science skills gap at primary school in the science knowledge of many teachers and their confidence to teach the subject (more than 95% do not hold a science degree). Primary teachers are expected to be both polyglot and polymath – a clearly unrealistic expectation.

In Ireland, the UK, other European countries and the USA there are programmes attempting to introduce STEM subjects to and engender enthusiasm in children for science, technology, engineering and mathematics. Of those aimed at primary school, however, most are sporadic, fragmentary and lack the persistence and continuity required to repair the system. Angela Lee Duckworth's work at the University of Pennsylvania has underlined the importance of persistence and grit in education (e.g. Duckworth, Peterson, Matthews and Kelly, 2007).

Against a background of limited and reducing resources and with increasing class sizes, the teaching of primary science is coming under increasing strain in Ireland. Add to this, the growing lack of high-quality graduates in many STEM sectors, and insufficient number of pupils studying more than one science at Leaving-Certificate (the terminal examination of post-primary education) level, there is a need for urgent action to grow capacity of a high-quality science workforce. These problems are magnified by the fact that many children, particularly girls, have developed negative attitudes to science by the age of 13. Consequently, the majority of our children, and indeed our society, are poorly literate in these areas. In industry this manifests as a shortage of suitable STEM-enabled graduates. In society it manifests as disconnection from fundamental aspects of our lives, the world around us, the resources on which we depend and critical engagement in planning our future.

SIAB aims to inspire young children with a truly exciting experience of science at home and school. Research on co-teaching science in primary schools shows that extraordinary results can be obtained through external specialists working closely with the normal classroom teacher (e.g. Murphy and Beggs, 2010). Hence, SIAB has adopted a co-teaching model whereby a scientist (typically a PhD science student or a scientist working in industry) plans, teaches and evaluates science lessons with the school teacher.

The scientist arrives at school once a week with a box of scientific materials, supported with engaging *PowerPoint* presentations and videos, and for an hour the co-teachers engage the children in exciting, sometimes difficult, science, such as the Big Bang and evolution. The programme content was designed to enhance the current primary school curriculum while complementing and leading into the new Junior Cycle science programme. It similarly addresses science as an overarching strand, and moves through the physical, chemical, Earth and space and biological strands, using the 'big history' of the universe both as a means of structuring the course and as a narrative device. The children receive a science journal at the beginning of the programme and are encouraged to follow up at home questions that arise in the classroom, do their own 'research' and attempt to find the answers themselves. Bringing science home with them is one way of extending their 'zone of proximal development' by encouraging reflection on their learning, collaboration with friends and family and linking science between home and school. The focus is on children's experience, and assessment is via quizzes and games.

SIAB was introduced initially in a small school in west Cork in 2006. It was the brainchild of a parent-scientist, who wanted to try out teaching 'rocket science' to children in 5th or 6th class, aged from 10 to 12. Each week, the scientist arrived with a box of science materials, tailor-made for children to use and take home with them (including bulls' eyes!) or for them to use in the classroom and keep there (for example, a roll of time made with kitchen paper, see Figure 2).

After a few years' experience in the classroom, this scientist teamed up with science education and other colleagues to develop a programme that involves (a) induction sessions for primary teacher–scientist teams to explore the materials and co-plan some lessons and (b) weekly lessons in school at which the scientist arrives with a box of science materials for pupils and the teacher (STEAM Education are also developing technology-, engineering-, arts- and maths-in a box programmes with similar format). The lesson is co-taught by the scientist and teacher, such that the teacher becomes more familiar with the science and the scientist with communicating science to children. There is no formal assessment, but there are quizzes, games and presentations from children. Informally, children were invited to answer some questions from the Junior Cycle science tests (national tests carried out at age 14–16). Some of their answers showed an unusually high level of scientific understanding. The pilot programme incorporated extensive feedback from teachers, co-teachers and children, evaluating the lessons and suggesting changes and additions as regards supporting resources, in order to maximise the enjoyment and learning outcomes for all involved.

Evidence from evaluating the pilot year of rolling out the SIAB in 22 schools in Cork, Galway and Dublin showed that most children were indeed inspired by being taught high-level science, despite the fact that some of it was very difficult for them. In addition, children from schools in which the co-teaching between scientist and teacher was more fully embedded were more positive about the experience. A full evaluation is underway currently. However, after the first six weeks, children in the Dublin schools were invited to write some comments about what they liked most and least. The sessions started with the Big Bang, and children created their roll of time made of kitchen

Figure 2 A section from the children's roll of time made with kitchen paper

paper (see Figure 2). They were introduced to the formation of hydrogen and the other elements from first and later generation stars, through to the final few years, when life began. The next few sessions examined more deeply the elements (see Figure 3), and introduced light and sound. Overall, comments from girls and boys were equally enthusiastic, although those from girls seemed to appreciate the learning more, while boys wrote mostly about the excitement. A few comments from this data illustrate some of these findings:

I really enjoyed chemistry. I loved the games that we had for making the elements. I learned lots of things that I wouldn't know until secondary school. I thought it was a great idea to do the

Figure 3 Playing the 'elements' game

games and I loved learning about the atoms, quarks, protons and neutrons. (girl)

I thought the chemistry was pretty cool, but I was slightly disappointed we didn't play with chemicals and we didn't blow something up. (boy)

I liked the chemistry because I liked the way you can find out how many protons and neutrons by looking at the mass number. I thought the games were good. But sometimes I found things confusing. (girl)

I really enjoyed the chemistry game because it was really fun. I especially liked how we could ask questions and (scientists) would answer them. Physics was awesome because it was really interesting to find out about how batteries work. (boy)

It was fun. The games made it easy. It was a bit hard to understand but it helped when you explained it. SO THANK YOU [child's capitalization]. (girl)

I really liked the Big Bang lesson because it explained how we started and how we formed and an idea of how the universe started from a tiny pinhead. (girl)

We were surprised at how much the children wrote about the scientific content so early in the experience. One of the most popular topic areas was the Big Bang and expanding balloons (see Figure 4). SIAB is about to expand into technology and engineering, and then mathematics and the arts. The science programme has so far involved mostly science PhD students as co-teachers, but in the longer term all programmes will include the option to be co-taught by scientists/engineers etc., directly from local industries. STEAM (Science-in-a-Box and other programmes) represents a strong partnership between schools, universities and STEM industry in pushing the boundaries of early intervention in school science. The early results are extremely promising in supporting the primary science curriculum in Ireland.

Figure 4 Expanding balloons

Conclusion

Transition from primary to post-primary science is never going to be seamless for all children.

Research studies internationally have indicated that children's enjoyment of science declines as they moved from primary to post-primary school (Jarman, 1997; Galton, 2002; Braund and Driver, 2005). A report on barriers to studying STEM by the Institution of Engineering and Technology (IET) stated that pupils entering post-primary schools report that the transition involves them becoming:

relatively passive recipients in the knowledge transition process with less and less time to do practical work. (IET, 2008: 3)

In Ireland, Varley, Murphy and Veale (2013) provided evidence from a survey of more than 100 pupils that their interest in science declined as they moved from primary to post-primary school. On comparing this with a similar decline in interest in school in general, it was revealed that overall the picture regarding attitudes for science was more positive than that for school in general. A consultation with young people on the reform of the Junior Cycle (Department of Children and Youth Affairs, 2011)revealed that, although science was one of the subjects pupils most enjoyed studying in primary school, it was not one of the subjects they would be most likely to continue throughout post-primary schooling. (The programme of study followed in the Junior Cycle leads to the Junior Certificate, the State examination taken at the end of the third year of Junior Cycle when pupils are 15 years of age.)

The Department of Education and the Department for Employment and Learning (2009) in their report on the Northern Ireland STEM review highlighted a similar decline in science interest between primary and post-primary level, but also illustrated effects of both gender and school type on these attitudes (Figure 5).

Overall, girls were more negative than boys in both school types. Boys were more positive about their enjoyment of both physics and chemistry in post-primary (non-grammar) schools, but more negative about physics in the grammar schools. (School types in Northern Ireland are grammar and secondary – the latter comprises all non-grammar schools.) Donnelly (2001) suggested that boys in secondary schools may have been more positive about science in secondary school because those not taking the transfer test were not the focus of the teacher's attention during transfer preparation. There was less change in enjoyment overall of biology, although girls in secondary schools were more negative. At the time this research was carried out, science was part of the selection test for grammar schools, which resulted in a focus on revision in upper primary science classes.

This article has introduced two innovations in Ireland to address the observed decline in interest in science experienced by many children after they enter post-primary schools, which focus on ways to support primary teachers to prepare children for post-primary science. Post-primary science is already moving towards a more inquiry-based approach, which foregrounds the importance of the nature of science. A strong focus on science as inquiry during the early years of post-primary, as well as in primary schools, can provide a way to smooth the transition between the two phases.

The potential for exciting and empowering children in the world of science at a young age could pave the way towards a future human culture in which there is a far higher level of scientific literacy than the present. The two innovations described here provide evidence of primary school children who discuss science and scientists in a way that introduces them to a world of science that has been constructed by humans asking and seeking answers to what they observe around them.

The first innovation, Nature of Science (NoS), involved class teachers who had completed a module in which they were prepared to teach NoS to children throughout the primary school. None of them were science degree-holders and yet they were able to work with the children on scientific puzzles and how to approach solving them using experimentation, creativity, imagination, speculation and teamwork. It provides an approach to teaching science in primary schools that is exciting for both teachers and children, without the requirement for degree-level knowledge of science. In Ireland, the revised

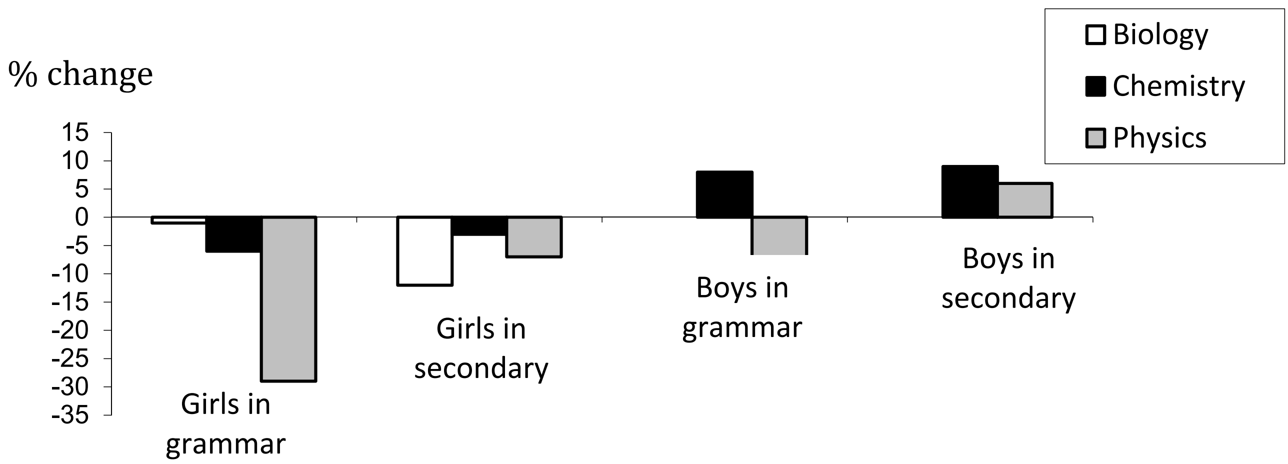

Figure 5 Overall percentage change in enjoyment of biology, chemistry and physics topics recorded by individual pupils as they progressed from primary to post-primary level (school types in Northern Ireland are grammar and secondary – the latter comprises all non-grammar schools)

specification for Junior Cycle science has a very strong focus on nature of science, which should pave the way for NoS to be introduced at primary level as the new specification is being developed.

The second innovation, Science-in-a-Box (SIAB), involves a programme of high-level science, co-taught by scientists and primary teachers. It incorporates NoS both as an introduction and to support children throughout in their quest for scientific knowledge and understanding. The teacher–scientist partnership empowers children to appreciate science as it is, in a way that they can begin to understand. There is no pressure to assess their knowledge of scientific facts; instead the programme seeks to inspire, excite and challenge the children. Future evaluation of this programme will seek to determine whether such early intervention impacts on children, as they get older in terms of subject choice.

Both innovations are designed to support, and not to replace, the primary/early post-primary curricula. SIAB is being extended to early post-primary schools once it has been rolled out fully in primary schools. Lessons we have learnt from children as they experience and talk about this work suggest some ideas for improving children's experience of transition between primary and post-primary science lessons:

- Introduce children to the nature of science activities early in primary school and continue to teach NoS throughout the post-primary phase.
- Introduce children to a broad framework for science, such as the 'big history' of the universe demonstrated through the roll of time made of kitchen paper (Figure 2) within which they can situate content. In our experience, starting with the Big Bang, formation of hydrogen and helium, supernovae and the formation of other elements, creating the kitchen roll of time and then using it to situate all aspects of science, helped children to make sense of their learning, even though some detail was difficult.
- Encourage and support children to enter science competitions, such as the BT Young Scientist and SciFest (www.scifest.ie).
- As far as possible, use games, videos, *YouTube* and other resources, which help children access the wonder and puzzlement of science.
- Encourage and support the development of and interaction between multiple skills and talents via team-based activities, mimicking real-world situations in which experts from many fields work together to solve scientific problems.
- Demonstrate via NoS activities ways that school science can mimic frontier science. Include as many links to science in the media as possible, which can direct children from school science towards the world of current scientific endeavour.
- Include much more investigative science in primary and early post-primary school. The work of Hans Persson in this area is excellent! For example, watch this: www.youtube.com/watch?v=7tJkltfO4tc.
- Develop joint CPD programmes for teachers of primary and post-primary science in which they learn more about what is done in each sector, and ways they can work together to facilitate transition for children.

While these innovations are still at an early stage and will require longer term evaluation to fully quantify the benefits, the evidence so far suggests that engaging primary school children with science in this manner encourages them to see and experience science as the dynamic, relevant, challenging and systematic process of exploration that it is. Children become more aware of the scientific process and how scientists work, exemplified by the comment quoted earlier: '*Scientists … are not always right, but they do their best.*'

References

Alake-Tuenter, E., Biemans, H. J. A., Tobi, H. and Mulder, M. (2013) Inquiry-based science teaching competence of primary school teachers: a Delphi study. *Teaching and Teacher Education,* **35**, 13–24.

Braund, M. and Driver, M. (2005) Pupils' perceptions of practical science in primary and secondary school: implications for improving progression and continuity of learning. *Educational Research*, **47**(1), 77–91.

Clerkin, A. and Eivers, E. ed. (2013) *National Schools, International Contexts: Beyond the PIRLS and TIMSS Test Results.* Dublin: Educational Research Centre.

Department of Education and Department for Employment and Learning (2009) *Report of the STEM Review*. Belfast.

Department of Children and Youth Affairs (2011) *A*

Consultation with young people on reform of the JC. Dublin: Government Publications.

Dewey, J. (1916) *Democracy and Education*. New York, NY: The Free Press.

Donnelly, E. (2001) *Management of Science Education during Key Stages 2 and 3*. MEd thesis, Queen's University, Belfast.

Duckworth, A. L., Peterson, C., Matthews, M. D. and Kelly, D. R. (2007) Grit: perseverance and passion for long-term goals. *Journal of Personality and Social Psychology*, **92**(6), 1087–1101.

Galton, M. (2002) Continuity and progression in science teaching at key stages 2 and 3. *Cambridge Journal of Education*, **32**, 249–265.

Institution of Engineering and Technology (IET) (2008) *Studying STEM: What are the Barriers*. Stevenage: IET. Available at: www.theiet.org/factfiles/education/stem-report-page.cfm.

Jarman, R. (1997) Fine in theory: a study of primary–secondary continuity in science, prior and subsequent to the introduction of the Northern Ireland Curriculum. *Educational Research*, **39**(3), 291–310.

Lederman, N. G. and Abd-El-Khalick, F. (1998) Avoiding de-natured science: activities that promote understandings of the nature of science. In *The Nature of Science in Science Education: Rationales and Strategies*, ed. McComas, W., pp. 83–126. Boston: Kluwer.

McComas, W. F., Clough, M. O. and Almazora, H. (1998) The role and character of the nature of science in science education. In *The Nature of Science in Science Education: Rationales and Strategies*, ed. McComas, W., pp. 3–39. Boston: Kluwer.

Murphy, C. and Beggs, J. (2010) A five-year systematic study of coteaching science in 120 primary schools. In *Coteaching in International Contexts: Research and Practice*, ed. Murphy, C. and Scantlebury, K. ed. pp. 11–34. Dordrecht: Springer Publishing.

Murphy, C. (2015) Reconceptualising the learning and teaching of scientific concepts. In *The Future in Learning Science: What's in it for the Learner?* ed. Corrigan, D., Dillon, J. and Gunstone, R. pp. 127–150. New York: Springer.

Murphy, C., Murphy, C. and Kilfeather, P. (2011) Children making sense of science. *Research in Science Education* **41**(2), 283–298.

Murphy, C. and Scantlebury, K. ed. (2010) *Coteaching in International Contexts*. Dordrecht: Springer.

Murphy, C., Neil, P. and Beggs, J (2007) Primary science teacher confidence revisited: 10 years on. *Educational Research*, **49**(4), 415–430.

Murphy, C., Lundy, L., Emerson, L. and Kerr, K. (2013) Children's perceptions of primary science assessment in England and Wales. *British Education Research Journal,* **39**(3), 585–606.

NCCA (1999) *Science: Social, Environmental and Scientific Education*. Dublin: The Stationery Office.

United Nations (1989) *United Nations Convention on the Rights of the Child*. Geneva: United Nations.

United Nations, Committee on the Rights of the Child (2009) *General Comment No. 12 The Right of the Child to be Heard.* Geneva: United Nations.

Varley, J., Murphy, C. and Veale, O. (2008) *Science in Primary Schools, Phase 2.* National Council for Curriculum and Assessment. Available at: www.ncca.ie/en/Publications/Reports/Science_in_Primary_Schools,Phase_2.pdf.

Varley J., Murphy, C. and Veale, O. (2013) At the crossroads: the impact of new Irish science curricula on first year post-primary students. *Journal of Research in Science Education*, **43**(1), 275–298.

Colette Murphy is Director of STEM Education Research and Communication at Trinity College Dublin. She has a PhD and two master's degrees, and has worked as a science teacher/teacher educator/researcher for 30 years. Email: colette.murphy@tcd.ie

Mary Mullaghy is a PhD candidate and teacher of STEM Education at Trinity College Dublin. She holds a master's degree in chemistry and previously worked as a science and ICT teacher in post-primary schools for 25 years. Email: mullagm@tcd.ie

Alice D'Arcy is Managing Director of STEAM Education Ltd, based in Cork Ireland, for the last two years. She has worked as a freelance educator and consultant in science, environment, animation and sustainability. She has a PhD and master's degree from University College Cork and a master's degree from the University of Edinburgh. Email: alice.darcy@steam-ed.ie