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Children Versus Curriculum: Who Wins?

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7.1 Introduction

Today's children live in a world surrounded by the mass media, encountering scientific words and ideas early in life. Jakab (2013) found 8 year olds had everyday understandings of molecules, and that some of this knowledge came from the mass media. Recent research involving Jenny Donovan and Grady Venville, using samples located in three Australian states, further highlighted this. The 141 children who completed a survey on their use of mass media were found to spend an average of 5 hours 10 minutes with the mass media daily, of which just over 2 hours was with television (TV). Despite being aged 10–12 years, 79% of the children

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watched crime shows rated for ages 15+, particularly *NCIS, Bones, Law & Order, The Mentalist* and *CSI*. Of the 62 interviewees, 89% knew of DNA, 60% knew of genes, and 97% knew or surmised that humans have DNA. Although the interviewees had minimal knowledge of the biological nature and function of DNA, 77% related DNA to solving crime, 65% related it to identification and family relationships (e.g. adoption, unknown soldiers, paternity) and 31% related it (particularly genes) to disease. The interviewees recognised TV as the source of their knowledge, citing particular TV shows.

Similarly, in an ongoing research project by Carole Haeusler and Jenny Donovan, concerning teaching atomic-molecular theory to primary students, in their pre-interviews some 9 year olds mentioned words such as atoms, elements, and even the Periodic Table. When asked where they had gained the pre-knowledge they had displayed in the pre-interview, the mass media, especially TV, was the third most common source after school and parents.

This acquisition of words and ideas from the mass media spark children's curiosity. Some 27% of the 62 interviewees (10–12 years old) in the mass media and genetics study (Donovan & Venville, 2012, 2014) had researched genes and DNA for themselves. This indicates children's readiness to learn complex science ideas that is not recognised or supported by current primary school curricula.

7.2 Literature Review

Inhelder and Piaget (1958) were noted for proposing that children pass through four stages of cognitive development. This work has been narrowly interpreted to mean that children are unable to grasp abstract concepts before they reach 14 years of age. Curricula from many jurisdictions around the world have been written to correspond with this narrow interpretation; so many abstract concepts are deliberately not introduced to children until they reach 14 years of age.

The Australian Curriculum: Science (Australian Curriculum, Assessment and Reporting Authority [ACARA], version 6, 2014) focuses almost exclusively on the 'what' of science in primary school, without exploring the 'why' and the 'how'. For example, in Year 3, the curriculum prescribes the introduction of solids and liquids to 8 year olds, along with the idea that heat causes a solid to change into a liquid. How is a teacher to explain why or how this happens as particle theory is not introduced until Year 8 (13 years of age) with atoms and molecules following in Year 9 (the 'magic' 14 years of age). This makes the familiar 'dot/particle diagrams' that typically show the difference between solids and liquids off limits, along with discussions of heat as energy and changes to the movement of particles within these different phases. If teachers introduce such concepts only at the macroscopic level, that is, by distinguishing solids and liquids on the sole basis of their observed appearance, they risk introducing misconceptions. Students could easily come to believe that solids and liquids such as ice and water are different things, rather than a change of state of one substance. Similarly, 10–12 year old children interested in genes and DNA will have to wait until they are 15 years old to find out more about these topics in school, as this is when DNA first appears in the Australian Curriculum: Science.

The new USA framework (National Research Council [NRC], 2012) describes science education from K-12. Students are first introduced to particles in Grade 5, and then elaborated as atoms in Grade 6. By the end of Grade 8, students should know there are approximately 100 different types of atoms, but even in this bold new curriculum, which aims to introduce core ideas in science, technology, and engineering from students' earliest schooldays, the details of atomic-molecular structure and the Periodic Table are still not tackled until Grade 9.

Yet there is evidence that children are most interested in science in primary school. Tytler and Osborne (2012) report research that indicates that children's interest in science peaks when they are 10 years old, and they form their career aspirations by age 13 or 14. Leaving the exciting aspects of science (the 'how' and the 'why' that explains how the world works) until they are 14 years and older risks losing them from the pipeline to higher education and careers in science. Several studies have shown the importance of early engagement with science (Maltese & Tai, 2010; Tai, Liu, Maltese, & Fan, 2006; Venville, Rennie, Hanbury, & Longnecker, 2013). The need for both scientists and a scientifically literate populace is indicated by the plethora of reports released in many different countries (e.g. Bull, Gilbert, Barwick, Hipkins, & Baker, 2010; European Commission, 2004; Fensham, 2008; Goodrum, Hackling, & Rennie, 2001; Millar & Osborne, 2001; OECD Global Science Forum, 2006).

7.3 Conceptual Framework and Methods

This chapter is not reporting a single piece of research. Rather, this is a retrospective look across a decade of different research projects to draw out any common threads that inform us about the desire and capacity of young children to engage with and learn complex science. Each project will be briefly introduced with referral to where more detailed accounts of the conceptual frameworks, methods, and findings are published.

To facilitate international comparison, Table 7.1 shows the relationship of school years to ages of children in Australia. From Term 1 2022, all Year 7 students in government schools will be catered for in high school, not primary school as has been the case.

Snapshots 1 and 2 are from the project by Jenny Donovan and Grady Venville, aiming to extend children's understandings of living things and inheritance. Snapshot 3 is from Jenny Donovan's doctoral project, supervised by Grady Venville, which continued from Snapshots 1 and 2 in considering how the mass media influences children's understandings of genes and DNA. Snapshots 4 and 5 are new research by Carole Haeusler and Jenny Donovan, aiming to verify the efficacy of a program designed by a specialist teacher, Ian Stuart, to teach atomic-molecular theory to primary students. The focus is on the attitudes and responses of the children to the new learning. All of the projects depicted here as snapshots received human ethics clearance, the informed consent of parents, and informed assent of the participants.

Table 7.1 Relationship of School Years (Grades) with Chronological ages in Australia

School Years	1	2	3	4	5	6	7
Ages (years)	6	7	8	9	10	11	12

Snapshot 1, 2004: A class of 16 Year 2 students (including a pair of identical twins) in a religious independent school in metropolitan Perth, Western Australia. English was a second language for all children and the class was considered remedial according to results in Year 1. Jenny had worked with their teacher before, so we collaborated to design two interventions for her class, one designed to expand their knowledge of the characteristics of living things, and the other to extend that to inheritance. See also Donovan and Venville (2005), Venville and Donovan (2007).

Snapshot 2, 2006: A group of 12 Year 5 students in a class of 30 from a state primary school in metropolitan Perth, Western Australia. We were not made aware of any of the children having particular learning difficulties. The whole class received a first intervention about living things, but only the 12 interviewees received a second intervention about DNA. See also Venville and Donovan (2008).

Snapshot 3, 2009–2011: A total of 141 students from Years 5, 6 and 7 from four samples in a range of locations (outback to the coast) in three Australian states were surveyed about their mass media use. Semi-structured interviews about genetics were conducted with 62 of these students. See also Donovan and Venville (2012, 2014).

Snapshot 4, 2013: A class of 26 Year 4 students (and one Year 1 by parental request) from an independent primary school in metropolitan Brisbane, Queensland, Australia. This was the first school in which we researched this program, and was a highly diverse class, with seven children diagnosed with various learning difficulties. See also Donovan and Haeusler (2015), Haeusler and Donovan (2017).

Snapshot 5, 2015–2016: After verification of our findings from Snapshot 4 in several other schools, we focused on whether an enthusiastic generalist primary teacher could implement this program successfully. This work is being prepared for publication.

7.4 Findings

7.4.1 Snapshot 1, 2004, Year 2 (Interviewer: Jenny) Living, Non-living and Once-living Things

Intervention 1: Pre-interviews showed these children were quite knowledgeable about living things, but offered only one or two characteristics as scientific reasons for thinking they were alive. More than half knew dinosaurs were once living, with three students using the word "extinct" and another four saying they had all died. They had difficulties with natural non-living things such as clouds and the Sun, and with foodstuffs such as carrots.

The intervention involved group work to ascribe up to six characteristics of living things to pictures of different things as if they were real. Field notes recorded that "the children set to with a will and completed the activity more rapidly than expected. There was some very productive discussion occurring with students giving good reasons why they thought something was appropriate. Reaching consensus whether each was LIVING, ONCE LIVING or NON-LIVING brought forth more valuable discussion and remarkably only one error resulted and that had been the subject of dispute within the group. Once the activity was completed, the results for the same picture (generally appearing in at least two groups) was compared, and discussed. Students were enthusiastic and happy that they had "answered so well".

The post-interview showed they were now very aware of the six characteristics of living things to which they had been introduced, and correctly applied them to new pictures of living things. All but two students could now explain once living, which had previously been difficult. They were overall more accurate with non-living things, but had not transferred what they now knew about the Sun to the Moon.

Intervention 2: Pre-interviews showed that most children understood that offspring are similar to their birth parents. None spontaneously mentioned DNA, genes or chromosomes as the means for this relatedness, and only a few children recognised the word DNA, none recognised genes (when clarified it wasn't the same as jeans).

After recapping the previous lesson, we were ready to move on to the crux of the lesson, how is it that babies look like their parents. Field notes recorded: "I told them that's what I was going to explain to them now. They seemed very attentive at this point, as if I was going to unveil a great mystery! I said they all contain a special chemical called DNA which is passed on from parents to babies. All living things have DNA and pass it on to their babies. Then I asked a few questions. Do people contain DNA? Yes. Do cats and dogs contain DNA? Yes. Do your bean plants contain DNA? Yes. The trees outside? Yes. What about the concrete floor? NO! The desks? NO! They're not living (explained to me with a degree of patience). What about once living things? Much thought for a bit, then the answer, 'well they must do when they just die cause they were once alive!' This excellent answer was much praised. What will happen to the DNA? 'It will rot like the body does'. I was impressed!"

In the post-interview two weeks later, all but one child knew that living things have DNA, and four remembered that once living things may have DNA. All but one knew that no one would have exactly the same DNA as them, except the identical twins. They also clearly related DNA to traits in cats.

7.4.2 Snapshot 2, 2006, Year 5 (Interviewer: Jenny) Living Things and a Wool Model for DNA

Intervention 1: In the whole class brainstorm of the characteristics of living things, field notes recorded, "They did quite well, coming up with most of the criteria fairly readily, though no one knew the word excrete (but had a range of colourful alternatives!). There were some spurious ideas, such as dies, sleeps, has blood etc. The idea that tree sap is equivalent to blood is well established in this group, and apparently is the result of teaching the previous year. However, eventually we weeded those false criteria out, and had a full set of correct criteria (even including 'contains DNA'—this came from one of the interviewees).

The post-it note activity was well done, the students took it very seriously and really enjoyed working with the pictures and the notes. The groups worked well together, if somewhat noisily, and there was much serious discussion about the difficult ones. The students felt free to voice their opinions and also to challenge and correct each other, generally in a polite way. Overall the results were good, with many of the misconceptions e.g. about the Sun, being corrected within the group before consensus was reached. The discussion following the activity was opportunity to challenge the interesting answers that had been arrived at by consensus in groups 4 and 5. It was good to hear some students actually saying 'yeah, well I thought that too, but x says that a cloud is just made of water and it doesn't need food so it can't be alive' and other such statements, showing they had taken on board the ideas of others when found to be superior to their own".

Intervention 2: Given the range of abilities diagnosed during intervention 1, the second lesson was given to the interviewees only. Field notes recorded, "These students were very excited about this lesson and asked a phenomenal number of questions. We reviewed the characteristics of life, recalled that they understood that offspring resemble parents, and that some of them had heard of genes and DNA but didn't know much about them. They were well behaved with their wool models, treating the process of assembling their 'DNA' very seriously, though some had trouble with tying the knots. Once shown, they were quick to learn. They readily saw that no one had the same DNA, and found it easy to identify the genes and the number of different alleles for the genes. The four terms presented seemed to be well understood. They even noticed that people were homozygous and heterozygous for certain traits, although they didn't know the terms. I mentioned them in passing, but pointed out that this was significant in terms of inheritance, as some alleles would show up in the offspring, whereas others wouldn't".

Their interest was such that that one child followed me out to the carpark still asking questions. The level of interest and excitement was amazing and they raised ideas and issues that I would have been excited to see in a Year 11 class. Post-interviews showed uptake of all required knowledge in all but two students. These two had partial uptake, but did not spontaneously mention genes/DNA as the means by which offspring resemble parents.

7.4.3 Snapshot 3, 2009–2011, Years 5–7 (Interviewer: Jenny) Genetics Knowledge and the Mass Media

Students readily acknowledged mass media, particularly TV, as the source of their genetics knowledge. However, I was surprised to learn that 27% had become so interested in the topic that they had done their own research, resulting in highly detailed understandings. Only a few excerpts of some children's own words are quoted here. All names are culturally appropriate aliases.

Tobias, Year 5: I know that they're doing research with DNA, taking DNA out of dinosaur bones and putting it in like rats and mice. Because then, hopefully when they breed them, that dinosaur DNA will pass on and will probably start getting the effects that the dinosaurs would look like, to find out more about them. I know that they can use it … there's technology now, you can get the bones, get the DNA, do a special scan and actually find out what the person looks like.

Prasai, Year 6: I learned about DNA in my school in Malaysia in Years 1 and 2. I've also done my own research into it; I got interested, and used the Internet. Well, you can take fingerprints; that's a DNA sample. You can use genes to find the family. To identify people, scientists could use a very technical, advanced computer, and get samples of DNA that might be on fingerprints, and use the computer to find out how the person looks.

Willis, Year 6, from a long and highly detailed interview, including an accurate description of taking a biopsy for cancer: I learned about DNA from books, programs, and just from going on the Internet, from DNA books, there are books about DNA. Also from DVDs … I know *Catalyst*[1] has some things on DNA and all that. And like if I was on Google, I just type like DNA or genes into the search box and it comes up with loads of sites, full of lots of words that I cannot pronounce. Like what DNA stands for, I still cannot pronounce. (He could by the end of the interview and was most pleased).

Anton, Year 6: They use DNA for forensics. But is there dead DNA? I'm not sure what happens to DNA when they die. DNA keeps us alive.

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[1] *Catalyst* is an Australian TV show that focuses on science concepts and innovations.

We use DNA to identify ourselves. Can also use DNA to clone dogs, you use the DNA of the one you want to clone.

Brian, Year 6: If you don't have any DNA you'd be under a gravestone. But when you're dead you still have some DNA in your bones. I've seen DNA on science shows and crime shows on TV, and then I looked DNA up on the Internet and read it in books.

Annette, Year 7: The chromosomes and the DNA I heard about in health, also some of it I learned from my parents, like if I watched a certain TV show and it might have spoken about some things I don't understand, like genes, or something, I might have asked them and they explained it all to me.

Saul, Year 7: Like we can do DNA fingerprints to solve crime. We can cross two animals' DNA to make another type of animal—like elephants and mammoths—can take mammoth DNA and put it into elephants. And in China, they're putting human DNA into robots. I don't really pay attention to TV though, it depends on what it is.

The last word goes to Paul, Year 5, from the most remote sample: Yes, I've heard of DNA, genes and chromosomes. Can use DNA to track soldiers who died in Gallipoli to see who they're related to. Can use DNA to make clones. DNA is in hair, blood, fingernails and in skin maybe. DNA is like a twisty ladder. DNA and genes are similar but their shape and the way they work is different. Can use DNA from healthy people for sick people, like blood transfers. It's in your fingerprints to solve crime, track guns or weapons. *I like that TV science like crime shows, teaches kids about stuff they'd only learn in college or high school. Then I looked it up in an encyclopedia.*

7.4.4 Snapshot 4, 2013, Year 4 (Interviewers: Carole and Jenny) Atomic Theory and Attitudes Towards Science

In this research, we directly asked students about their like/dislike of science. Table 7.2 shows their responses pre and post the teaching about atomic theory.

Table 7.2 Students' response about liking/disliking science before and after the teaching about atomic theory

Pre-interview	Number of students	Post-interview	Number of students
Do you like science?	24/27 yes	Do you like science?	26 Yes (7 now love it/ favourite)
Why?	Fun (14)	Why?	Learning about atoms & molecules (16), fun (7)
Science is about …			
Experiments/data	7	Periodic Table/ elements/atoms	22
Mixing chemicals/ explosions	7	Finding out new things/ how world works	10
Earth/volcanoes/ rocks	5	Experiments/data	7
Finding out new things/ how world works	4	Mixing chemicals/ explosions	1
Periodic Table/ elements/atoms	4		

The data in Table 7.2 show that science was well liked by these children before the teaching and even more so after it. This was expressed verbally in interviews in several ways, perhaps the most passionate being from an 8-year-old girl, "I LOVE the Periodic Table, I love it, I love it, I love it".

However, loving it is great but were they able to learn and understand the taught concepts? Figures 7.1 and 7.2 show the pre and post results of their understandings about atoms, molecules, and the elements (Donovan & Haeusler, 2015). The same legend applies for Fig. 7.2 as for Fig. 7.1.

In Fig. 7.1, the exceptional pre-knowledge is explainable as child 9 is the Year 4 brother of child 27, the Year 1 girl, present by her parent's request, as she is 'even more into science than her brother!' Child 8 is a friend of child 9 with some mutual interest and probable exposure to science. The speech and language impaired (SLI) children are numbers 15 and 23, with child 15 also struggling with intellectual impairment and child 23 also being ESL. It was expected that few children would score well as few were thought to have been exposed to these ideas yet, and it

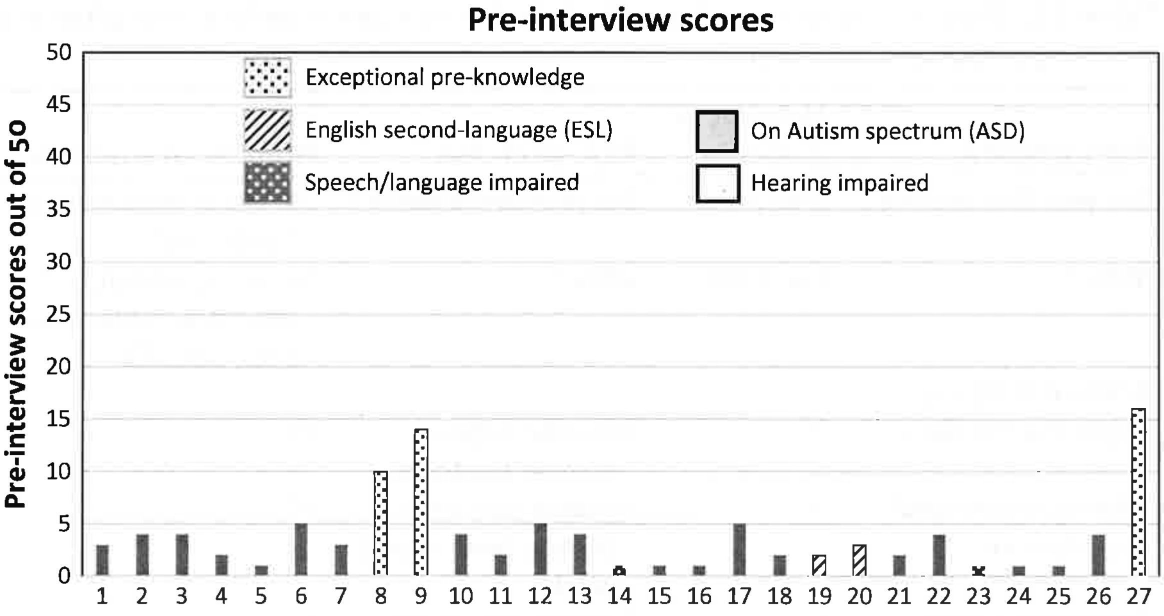


Fig. 7.1 Initial understandings about atoms, molecules, and the elements in the class of 27, which included 7 students with special learning needs and 3 with exceptional pre-knowledge

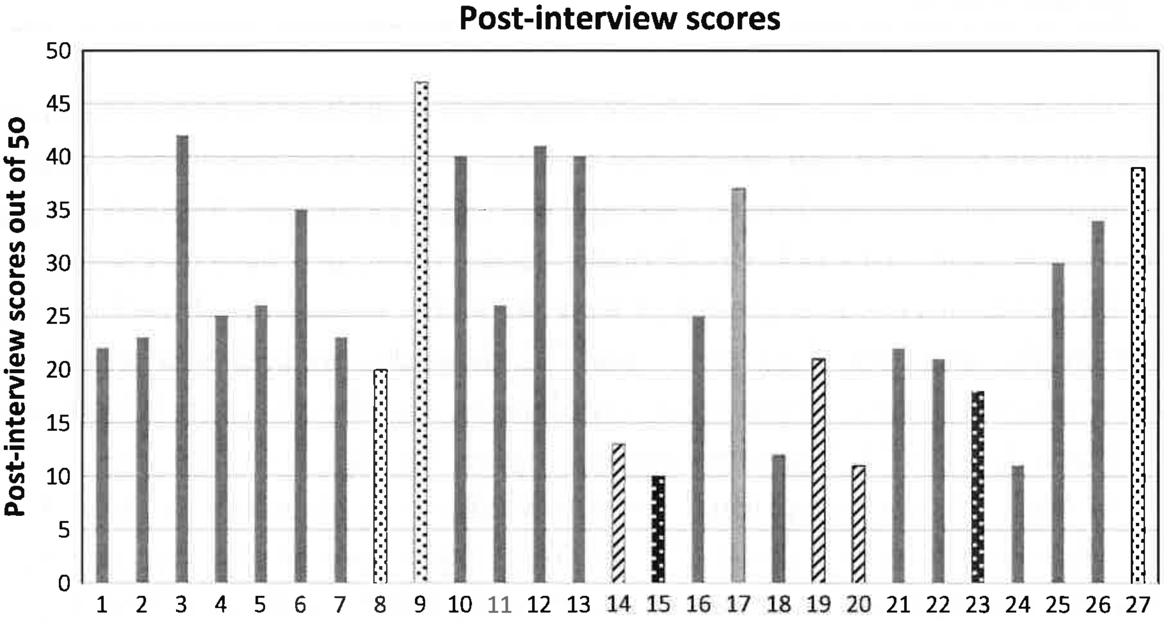


Fig. 7.2 Gains in understandings about atoms, molecules, and elements after the teaching

was carefully explained to the children that it was OK not to know, we just wanted to hear their ideas. Children often express this as 'I don't *know*, but I think ...'.

Figure 7.2 shows that all children gained knowledge and understanding including all with learning difficulties. Child 15 now knew 10 times as much as he started with and the classroom teacher suggested this was outstanding for him. His response was that he was so happy he could now tell the nice lady (Carole) what 'a natom is!' He really did know. Also of interest is how well child 17, who has ASD, did. The hands-on teaching using lots of models plus individual time to reflect and work things out really suited his style of learning. Child 9 was determined not to be outdone by his sister again and gained the highest mark, whereas his friend, child 8, was less motivated and did not build effectively on his pre-knowledge. However, for a 6-year-old (child 27) to score 39/50 on questions on Year 9 chemistry, is exceptional. Ian obtained special permission from her and her mother to film her for use in open-source videos to inspire others. One such video is available from https://youtu.be/2LfhSk5IJqM and others are available. Note her depth of understanding in her last statement about this being a real molecule, not hers. Similar philosophical depths were attained by children in schools next researched, including 'The Periodic Table is like ... the alphabet of the Universe'.

7.4.5 Snapshot 5, 2015–2016, Years 3/4 (Interviewer: Carole) Professional Development for Teachers

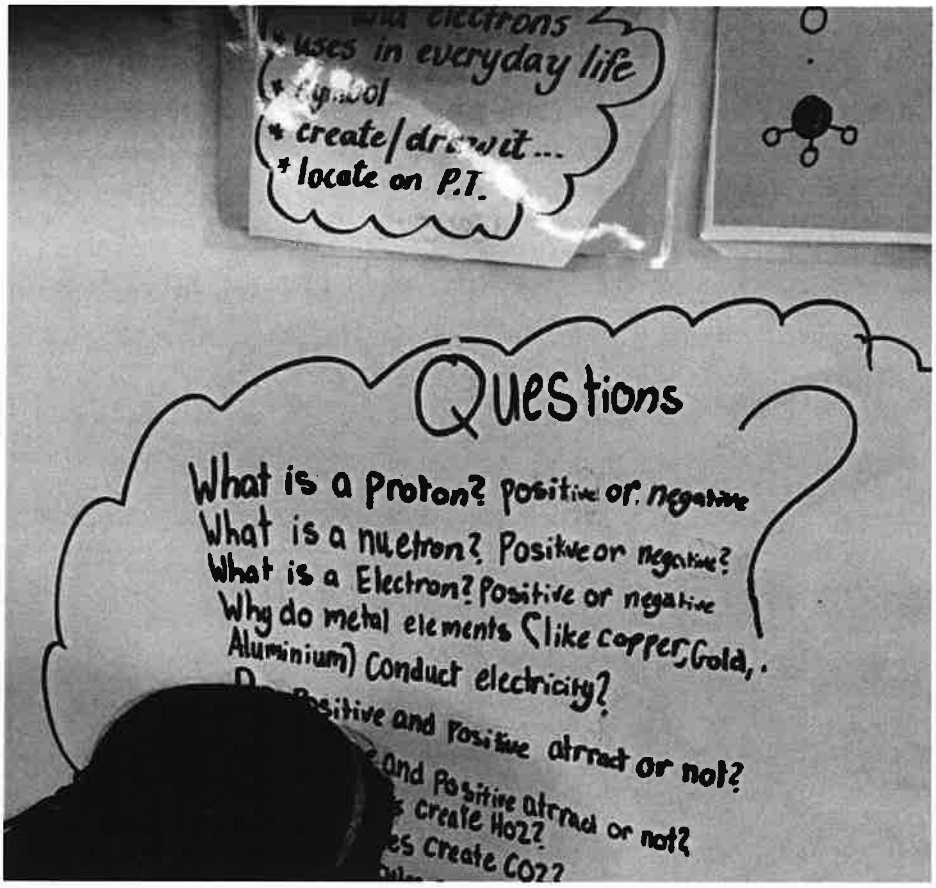
A criticism raised in response to the atomic theory work (Snapshot 4 and subsequent verification data) was that this was fine with a specialist science teacher, but could it be done by a generalist primary teacher? We were fortunate in that a school near Carole's campus had heard about the program and were interested. Both Carole and Jenny spent an initial day in the school providing professional development for every staff member, including the principal. We had them use some of the hands on models to complete some of the activities the children would do and they found these challenging but interesting. By the end of the day, the Years 3/4 teacher was enthusiastic to take it on. With the support of the whole school, it was agreed that she (M) would do so. Carole, being nearby, was ideally positioned to offer support (although this was much less than anticipated) and to transfer sets of models between her and the specialist science teacher.

There were two obvious differences between her approach and that of the specialist science teacher. 1) M employed much more 'primary-style' pedagogy to great effect, including devising alternative forms of the models and allowing more consolidation time; however, 2) this resulted in less coverage, particularly of molecules. This was evident in the interviews, although some children had grasped the idea of how atoms bonded together to make molecules, not all had. However, in the bulk of the interview, where the same material had been covered, M's children scored on par with children of the same age range taught by the specialist. This was a particularly exciting finding for us as it indicated the program could be transferable to generalist teachers.

M's further reflections also provide insight to the children's responses:

- The children were very excited and enthusiastic to learn about atoms, molecules, and the Periodic Table [reflected in questions we asked them, they loved it]
- I was astonished they had no great difficulty with particulate nature of matter [so in later iterations the school is tackling this in Year 2 to help explain states of matter as a precursor to atoms in Year 3]
- I feel I will do much better next time around—I'm keen to repeat it [and she has done so, twice]

The children worked at their own pace to achieve the success criteria for each lesson so there was no piece of work that was the same for every child. Nonetheless, a look through the childrens' workbooks showed their level of learning was consistent with that seen in children from other schools and with what they demonstrated to us in the interviews. Figure 7.3 shows one student posing questions to be answered by investigation on the whiteboard, where Fig. 7.4 demonstrates one student's understanding of an oxygen atom. Note the inclusion of labels of 'nothingness' between electrons. Following a lesson on covalent bonding, where the teacher explained how atoms can share outer electrons, one



electrons

* uses in everyday life

* symbol

* create/draw it...

* locate on P.T.

Questions

What is a Proton? positive or negative

What is a nuetron? Positive or negative?

What is a Electron? Positive or negative

Why do metal elements (like copper, Gold, Aluminium) Conduct electricity?

sitive and Positive atrract or not?

and Positive atrract or not?

s create H2O?

es Create CO2?

Fig. 7.3 Engaged student posing science questions (permission granted for this photograph)

boy excitedly showed the teacher how he had worked out that sodium could give an electron to a chlorine atom so that both atoms would have full outer shells, thus extending to ionic bonding.

7.5 Discussion

Collectively, these snapshots yield considerable evidence of the interest young children have shown for more than a decade in learning advanced science subject matter and how quickly they were able to take up the ideas. Common threads include:

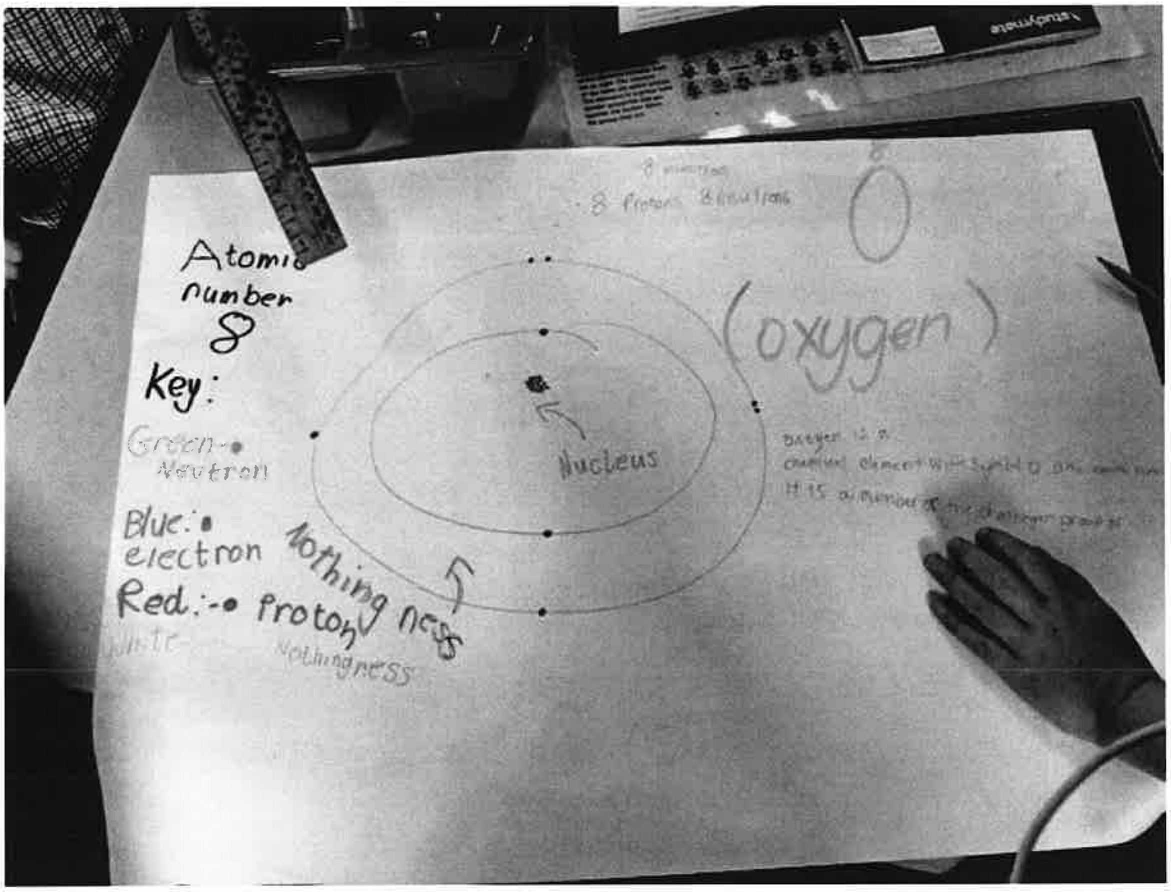


Fig. 7.4 One student's symbolic representation of the internal structure of an oxygen atom (permission granted for this photograph)

1. The excitement and engagement levels of the children are very high when presented with 'real science'. Teachers commented that they had rarely seen the whole class so engaged.
2. Children love learning high school science and several in Snapshot 4 reported their pleasure at being able to help their 14-year-old siblings with their chemistry homework. Some in Snapshot 3 had researched high school level science (genetics) for themselves, indicating their strong desire to learn at a higher level.
3. Many reported wanting to know 'how the world works', indicating a desire for an explanatory framework for how and why. This is more than the 'what' aspect of science offered by the Australian Curriculum: Science (ACARA, 2014). This desire for explanation of how and why was also a key factor in why scientists became scientists, who mostly

reported their passion for science starting at primary school age (Venville et al., 2013).

4. Beyond a desire to know, children showed remarkable capacity to know and understand the content presented, which far exceeded our initial expectations. We believe that the use of age-appropriate hands on activities and models greatly facilitated this, and children were able to draw and manipulate the models during the interviews to help explain what they meant. Here, they were at an advantage over their older siblings, for whom the topic was reported as being taught in a theoretical style focusing on symbology.

Our work covers half of the science curriculum, biology and chemistry. There are others working in these areas such as Kelemen's group in natural selection (2014) and Jakab in molecules, and many more. Bordering chemistry and physics, Weiner's team (2017) has exposed 12-year-olds to quarks and elementary particles. Blair (2012) has successfully taken Einsteinian concepts to primary school, citing the need to expose children's minds to spacetime and relativity before they become 'Newtonised'.

This latter approach to physics shows there can be two ways of implementing this revolution. Those in biology and chemistry are following Bruner's (1960) belief in a spiral curriculum: Break the big idea of science down into useful chunks, sequence the chunks, then teach them so each is reviewed and built upon to achieve the whole idea by end of school. This may involve teaching at macroscopic, microscopic, atomic, and symbolic levels at the same time. The children in our studies demonstrated a remarkable capacity to grasp these different levels, given that teachers explicitly showed these levels and the nature of the information gained from each one. By contrast, Blair's approach is to jump in at the deep end, plant that seed very firmly, and then go back and show how scientists reached similar understandings. See also Foppoli et al. (2018) for teacher and public responses to the Einstein-First program.

What is the value of such interventions? How do they influence students? Can they solve our national problems with STEM? We could write another chapter on the links between STEM in schools, reasons why Australia is not meeting targets for STEM in higher education and careers, and the putative value of such interventions. There is research evidence that more young people, exposed to quality teaching of science, would go on to become scientists or work in STEM-related fields, although this is scattered and localised. There is a pressing need for such research to be more clearly reported and widely disseminated to teachers as well as to policy-makers. We need more schools to adopt these interventions to collect meaningful longitudinal data regarding their longterm influence on students' choices. To provide a succinct overview of the challenges Australian schools face, we abstracted the following comments from the comprehensive report that Timms and colleagues wrote for the Australian Council for Educational Research [ACER] (Timms, Moyle, Weldon, & Mitchell, 2018).

- Australia is one of many countries seeking to improve STEM literacy, subject uptake, and transfer to careers.
- Improving STEM comes from survival need (for STEM workers who can solve complex real-world problems) and for the economy (nations without such workers face huge financial challenges)
- Yet enrolment in senior science subjects has been declining since at least the early 1990s and is continuing
- Scores on national and international tests in science and mathematics are falling (despite the introduction of many initiatives and the NAPLAN testing for mathematics)
- Socioeconomic status, closely linked with location, is a major factor in determining how well students achieve in science. Children in low socioeconomic areas (including many rural and remote areas) can be as much as three years of schooling behind their high socioeconomic counterparts
- Early intervention is necessary. Knowledge gaps that exist when children first step into school persist
- The gender gap has long been recognised, with fewer female students opting for science subjects. Many interventions have been introduced although until recently, most of these were aimed solely at high school students. There is growing recognition that science education must occur from pre-school onwards, and this seems particularly important for girls [we noted in our studies that girls were just as excited and

capable as the boys, and very little evidence of science anxiety in either gender]

- The report calls for improved assessments in science skills (including practical or digital assessments), and improved monitoring and research of the results
- There also needs to be improved monitoring and dissemination of results of interventions, successful or not. [In this, we have been publishing our research for some years].

A look at the Australian Government's response to these issues is very telling (see https://www.education.gov.au/support-science-technology-engineering-and-mathematics). There are some useful initiatives here and some funding provided, but there is an elephant in the room. No where do they mention closing the 3-year gap for all students in low socioeconomic circumstances.

7.6 Conclusion

In Foppoli et al. (2018) one public comment from an Australian reader expresses the central tension presented in this chapter succinctly:

> *Given the discovery of gravitational waves only happened this year, the reason we don't teach Einstein's theories in our schools is because of the exorbitant amount of time it takes to develop and approve curriculum in this country.*

Exactly. All the research in Australia and overseas, indicating the need to smash the ceiling on children's learning imposed by the curriculum comes to naught if the curriculum itself is unchanged. Yes, teachers can teach beyond the curriculum, but radical reorganisations of sequence would have to be agreed upon by a whole school and mapped so that ultimately the school can sign off that what is mandated has been taught. This takes a great deal of curriculum understanding and confidence. The Review of the Australian Curriculum (2014) was quite scathing about aspects of the curriculum and the way in which it was developed (justifiably, based on thousands of submissions received). However, sadly, the need to take note of current research in subject areas does not seem to be part of the new review/rewrite agenda. At present, and for the foreseeable future, the ancient juggernaut that is the curriculum is still winning. Children are not being given the appropriate opportunities to demonstrate their full capacity when the curriculum imposes any ceiling, let alone a ceiling as low as in Australia's current science curriculum.

With a rewritten science curriculum that takes into account what research has demonstrated children can do, they could

- Have a far better grasp of the big ideas of science,
- Be more able to relate the science they are learning with what is happening and what they are seeing in everyday life, and
- Possess a love for science having been powerfully engaged with science.

It is acknowledged that the national trends will be extremely difficult to reverse. However, for a step in the right direction, we need to put the children first. Let them drive their capacity to learn by offering them the opportunity to tackle exciting and real science ideas such as atoms, genetics, and spacetime, with the knowledge that this has been successfully done in real Australian primary classrooms.

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