~ Scientific Literacy: Learning Lessons from a League Leader ~

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“***Science must be the servant and not the master of man.***”

Winston Churchill.


教养孩童，使他走当行的道，就是到老他也不偏离。箴言22:6
Train up a child in the way he should go , and when he is old he will not depart from it . Proverbs 22:6
核心价值观
圣洁·公义·敬·忠·信·
CORE VALUES
Holiness • Righteousness • Respect • Loyalty •
OUR BELIEFS
Every student has talent
Every student can excel

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1.Abstract

I am a full-time science teacher with a background in research science and some experience in international education research. For long I have had an interest in developing my knowledge of the most effective techniques to better engage and further the understanding of the students I teach.

Recently, a new term has entered the science teacher's vocabulary: *Scientific Literacy*. This encompasses not only the material content of science, but places an increased emphasis on its procedural and so-called epistemic natures; namely, how scientists go about generating findings and how we, as citizens, ought to interpret them. Needless to say, such skills are becoming more important in our increasingly scientific and technological 21st century - with some suggesting that these skills are vital for our country's future economic prosperity.

The re-emergence of this term is perhaps not coincidental, however. In late 2015 a global survey of student ability, called the Programme for International Student Assessment (PISA), will be administered to students around the world. For the first time in nine years, the main focus of this test will be Scientific Literacy. If past results are anything to go by, when the results are published in late 2016, newspapers will run front-page stories comparing our students with their peers abroad. Unfortunately, they will likely show that our young people have fallen further in the rankings.

Countries including Singapore, which celebrated its 50th Anniversary of Independence in 2015, spend far less of their GDP on education, have larger class sizes and follow curricula and undertake examinations developed here in the U.K. However, all evidence suggests that once again they will be among the league leaders.

It is my hope that this report, which is based on my observations and discussions in four Singaporean schools in the summer of 2015, will cast some light on the means and mechanisms by which teachers help develop Scientific Literacy in their students. The intention was to afford me with fresh ideas for my own teaching, and provide new perspectives for those I work with and others further afield in the U.K.

2.Introduction

2.1. The Background of the Fellowship

“*Today, because of rapid economic and social change, schools have to prepare students for jobs that have not yet been created, technologies that have not yet been invented, and problems that we don't yet know will arise.*”

Andreas Schleicher, CEO of the OECD, 2012.

As our global population increases, the generations of tomorrow will encounter fresh challenges. How shall we increase food production? Where will our future energy come from? And how can we best treat the ailments of an ageing population? Indeed, most of these issues will have a scientific dimension. Hence the purpose of science education in the coming decades may not be provision of routine cognitive skills for all. Rather, more important may be to ensure that learners are prepared with skills, interpersonal and decision-making among others, that will equip them to craft innovative solutions for the problems that we will undoubtedly face.

That is not to say that all members of a future society will be directly involved in tackling these scientific issues. Granted, the traditional role of a science education in school has been ‘prevocational;’ the identification and preparation of those with special aptitude for the subject. However, perhaps as important in the future is perhaps to be an informed and responsible citizen, capable of understanding science-related issues. It is, after all, all members of society who are able, at least in democratic countries, to have a say in the policies and decision-making of their governments. But on a more individual basis, generations of the future will need to make more and more decisions in relation to a range of issues with a scientific dimension: healthcare, personal safety, lifestyle, consumer choice, and so on. All would be better placed to address these concerns if they have some understanding of how scientists generate data and arrive at conclusions. This will permit those to be able to decide whether the many claims made in the media have been derived using appropriate procedures and are ultimately warranted. In short, it is important that both future generations of scientists and engineers, but also the wider general public, are *scientifically literate*.

The concept of Scientific Literacy comprises a broad range of facets: a knowledge of major concepts and ideas that form the foundation of scientific and technological thought; how scientific knowledge has been derived; and the degree to which such knowledge is justified by evidence or theoretical explanations. In light of this, two questions emerge. First, *what is the present standard of education in the U.K. with regards to Scientific Literacy*; and second, *how could it be better developed in British students?*

In relation to the first question, perhaps the most notable pieces of evidence of the standing of British students with regard to this concept has been our consistently lacklustre standing in the Programme for International Student Assessment (PISA). PISA, which is operated by the Organisation for Economic Co-operation and Development (OECD), evaluates education systems worldwide every three years by testing the skills and knowledge of 15-year-olds in the key areas: reading, mathematics and scientific literacy. In the most recent sitting, the results of which were published in December 2013, the United Kingdom was ranked 20th in the world for scientific literacy. This places us behind countries such as Poland and Vietnam, which have a less established education system, and others such as Germany, Australia and Canada, which spend less per pupil on education. Occupying the top positions are consistent high performers, particularly East Asian countries such as Hong Kong, Taiwan and Singapore. These results are echoed by other surveys, including the Trends in International Mathematics and Science Study (TIMSS). Many are concerned that the U.K. should register a ranking so low, particularly as it occupies a higher position in the table with regard to education expenditure, parental background and many other relative measures that should impact positively on children's educational gains.

Regarding the second question, like many science teachers in the United Kingdom I was fascinated by the recent PISA results and questioned why British students were apparently lagging behind in their learning compared to their peers in many other countries. Having undertaken research into educational practice and teaching pedagogy, including in international settings, I was particularly interested in comparing our system with that of another. Uncovering lessons we could learn from such a country that consistently scores highly in international league tables seemed a fruitful pursuit. My application for a Churchill Fellowship hence centred on my interest in the consistently high ranking of one country in particular: Singapore. This small country was quick to recognise in the early 1990s that effective learning in science is not of the 'rote and regurgitation' variety, and its students regularly report high levels of enjoyment and satisfaction with their education. Moreover, the Republic uses English as its language of transmission in school, enabling deeper levels of professional dialogue with both students and teachers. It also follows a legacy of the British education system in its structure and employs curricula and administers examinations developed in the U.K. My feeling was that any findings I made would be more relevant given these considerations, and hence easier to translate into the British education system. Finally, Singapore celebrated its Golden Jubilee in 2015. It was therefore a very symbolic year in which to visit the country, with the spotlight firmly shining on how this country has achieved such great success in such a short time. **Appendix 1** provides further information on the country of Singapore.

The purpose of this report is to reflect on my findings and discuss the practices and procedures that may be transferable to the U.K. It is beyond the scope of this report to consider wider issues, such as the reliability and legitimacy of the PISA system. Undoubtedly, global surveys have their critics who question the reliability of the rankings (for example, Jerrim, 2011), but many people take the PISA results very seriously. Indeed, there is a growing sense of concern within the British education system that things could be better. The fact that the UK is lagging behind other nations made headline news in December 2013 and in response the Welsh Government published a document "*PISA Scientific Literacy: A Short Guide for Key Stage 4 Teachers*," comprising an overview of the assessment framework and even example questions, in the run-up to the sitting of the next PISA instalment. In the autumn of 2015 students across the world were selected to undertake the next instalment of PISA which, for the first time since 2006, had as its primary focus ('major domain') Scientific Literacy. Hence around half of the questions in the 2015 PISA test assessed Scientific Literacy. It is without doubt that those involved in education are eagerly awaiting the results of the recent sitting, which will be published in late 2016.

2.2. What is *Scientific Literacy*?

The media often plays a more significant role in the general public's understanding of science than the scientists themselves, and not always in a responsible way. Within the past year the general public has had to interpret, among many others, the controversial findings of studies that studied cancer rates, the claims and counter-claims regarding the reasons for climate change, and even claims that bacon is as deadly as asbestos! It is on such a backdrop that many educationalists have argued for improvements to the development of students' Scientific Literacy during their time in school.

Scientific Literacy has become an international slogan and a contemporary educational goal. A possible short definition of the concept is 'what the general public ought to know about science.' However, its exact nature is more complex than this. Viewpoints in the education community range from those at one extreme, who believe all students should study at least one science up to the age of eighteen, to those at the other who believe that '*the most valuable aspects of a scientific education are those that remain after the facts have been forgotten*' (Gott & Duggan, 1995). However, the reality is likely to be somewhere in between these two perspectives and encompass skills such as enquiry, evaluation and scientific debate. The literature regarding the concept is vast and there are some excellent synopses, including those by Bybee (1997) and Laugksch (2000). The framework employed by the OECD to inform its PISA examination questions draws on this wealth of thinking and international research (**Appendix 2**).

According to this framework, a *scientifically literate* student should be able to demonstrate three competencies. They should firstly be able to explain phenomena scientifically, namely to recognise, offer and evaluate explanations for a range of phenomena (so-called 'content knowledge,' which has as its focus the facts, concepts, ideas and theories that science has established). Second, they should be able to evaluate and design scientific enquiry, that is, describe and appraise scientific investigations and propose ways of addressing questions scientifically (so-called 'procedural knowledge,' namely, how scientists generate findings through empirical enquiry, and an understanding of terms such as variable, control and error). Finally, they should be able to interpret data and evidence scientifically: they should be able to analyse and evaluate data, claims and arguments in a variety of scenarios and draw appropriate scientific conclusions (so-called 'epistemic knowledge,' or an appreciation of the role that arguments, observations, theories, hypotheses, models, and questions play in science).

But how are these competencies best measured? It is beyond the scope of this report to consider the legitimacy and reliability of measures of Scientific Literacy. The distinction between 'education through science' and 'science through education' is well-documented (Holbrook & Rannikmae, 2007). Jenkins claims that '*the process of integrating it [scientific knowledge] with personal judgments and values and with situation-specific knowledge frequently relocates science as a peripheral player*' (Jenkins, 1997). On the other hand, it is notable that Millar puts forward data to suggest that the amount of knowledge of school science is the strongest predictor of civic scientific literacy in adults (Millar, 1997). Perhaps the most appropriate way to contextualise the concept of Scientific Literacy for this study is to link it to the National Curriculum in England:

'*A high-quality science education provides the foundations for understanding the world through the specific disciplines of biology, chemistry and physics. Science has changed our lives and is vital to the world's future prosperity, and all students should be taught essential aspects of the knowledge, methods, processes and uses of science. Through building up a body of key foundational knowledge and concepts, students should be encouraged to recognise the power of rational explanation and develop a sense of excitement and curiosity about natural phenomena. They should be encouraged to understand how science can be used to explain what is occurring, predict how things will behave, and analyse causes*.'

National Curriculum in England, Department for Education, 2013.

This description recognises the importance of science education and moreover places emphasis both on learning the *content* of science (facts, figures and theories), but also the *concepts* of science (methods, skills and uses). Refreshingly, it also reserves a position for the *enjoyment* of working scientifically and sustaining their interest in it, placing excitement and curiosity as key foci. In a statement that echoes aspects of Scientific Literacy, it is argued that students taught in such a way would be far more likely to continue to study science and use that learning for work and in the home, and making decisions and acting as a responsible member of their society. This chimes with definitions as provided in many synopses and, indeed, that provided by the OECD itself: '*the capacity as a reflective citizen to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and changes made to it through human activity*' (OECD 2000, p. 76).

However, despite the sound intentions of the English National Curriculum, a recent, critical Ofsted report found that such approaches were lacking in many secondary schools (Ofsted, 2013). One significant effect of this was that few students choose to study science beyond the age of 16. The report found that too few students in schools were able to discover scientific concepts through observing scientific phenomena and conducting experimental investigations for themselves, and as such students were '*poorly prepared for any science learning or for any job that involves science*.' Even in those schools in which grades were highest and students were working hard, many were not *enjoying* science and hence understanding was uninspired and superficial. Most rarely extended beyond the examination specification, prohibiting students to follow leads they had suggested themselves to satisfy their curiosity. "*Getting the grade is not the same as 'getting' the science*," is how the report describes the overall situation. Throughout this report I will make reference to this recent Ofsted report, as an accurate indication of the most up-to-date practice in British science education today, in order to draw direct comparisons with my observations in the classrooms of Singapore.

2.3. Aims of the Fellowship

My Fellowship had as its primary focus the observation of day-to-day practice in four schools in Singapore, of a range of characters. **Appendix 3** provides a background of the four visited schools. The short-term aims of the Fellowship were to gain an understanding of the following components of the science education system in Singapore. The hope was that these would act as a reliable measure of the quality of provision in terms of developing students' knowledge and understanding of science in general, and Scientific Literacy in particular:

1. The Singaporean education structure and its aims.
2. The Singaporean curriculum and assessment methods.
3. The training and continuing professional development of teachers in Singapore.
4. The role of Heads of Department in Singapore.
5. The teaching and learning strategies employed within Singaporean classrooms.

In addition to these aims I was also interested in discovering other factors that may help explain the academic successes of the Republic.

Although the primary focus of the Fellowship is to inform our practices in the U.K. with regard to developing students' Scientific Literacy, the long-term aim of the Fellowship is to enhance the teaching of science and other subjects more generally by learning from the Singaporean education system.

3. Findings

3.1. The Education System in Singapore

"*A nation's wealth in the 21st century will depend on the capacity of its people to learn.*"

Prime Minister Goh Chok Tong, 1979.

I gained an understanding of the context of Singaporean education through many fruitful discussions with Principals and Heads of Department. It was striking how each person knew the history of the education system, and indeed the country itself. I wondered whether such a deep knowledge of the trials and tribulations experienced by the Republic in its early years, and the success it has crafted for itself later, may in part underpin the sense of direction and drive of those with whom I spoke.

When Singapore became independent in 1965, it was a poor, small tropical island with few natural resources and rapid population growth. Today, Singapore is a world-leading hub of trade, finance and transportation. The transformation of this '*little red dot*' in one generation, on a background of marked racial and socio-economic diversity, is one of Asia's great success stories (Lee, 2000). Education has consistently been the building block for economic and national development during the past fifty years. Lacking other resources, human resources are seen as its most precious asset. It delivers of the human capital engine for economic growth and to create a sense of Singaporean identity, and the economic goals of education have given education policy a very strong focus on the future; in particular, scientific and technical fields. Perhaps as a consequence, the Republic ranks consistently in the top three countries worldwide for a range of school subjects, as measured in surveys such as PISA and TIMSS.

In Singapore's education system today, students receive six years of primary education, and four to five years of secondary education, followed by two years at a Junior College, Polytechnic or an Institute for Technical Education (**Appendix 3**). Primary education consists of a four-year foundation stage during which all students follow a common curriculum that emphasises English, mother-tongue language and mathematics. Science is introduced from the third year of Primary School. Subject-specific banding from Year 5 onwards is designed to allow students to progress at their own pace. At the end of Year 6, all students sit for the Primary School Leaving Examination (PSLE) in English, Mathematics, Mother Tongue Language and Science. Based on the results of this examination, students are placed in a secondary school that suits their learning pace and aptitude. Needless to say, there is a great degree of competition between students and their parents when it comes to preparation for the PSLE and securing a place at a more desirable secondary school.

In secondary school, based on the results of the PSLE and subsequent assessments, students are directed to follow one of three routes: express (60% of students), normal academic (25%) or normal technical (15%). Students undertaking the express course follow a four-year programme culminating in the general certificate of education (GCE) O-level examinations in Year 10. Students in the normal academic course follow a five year course, in which they study the same material but at a slower pace, and hence sit their O-level examinations in Year 11. The normal technical programme prepares students for technical higher education, jobs or the postsecondary ITE after a four-year programme leading to the GCE-N level examinations. Gifted students may study in one of several Integrated Programme Schools (two of my visited schools, Anglican High and Dunman High, are two such institutions). Here, they can skip O-levels and complete their studies with just A-Levels. It is claimed that this arrangement frees up extra learning time to allow them to engage in broader learning experiences that develop their leadership potential and capacity for creative thinking. Of note, there is now more horizontal mobility between courses; students who do well or underperform can be transferred. In all cases, examinations are written and assessed by a partnership between the University of Cambridge's International Examinations board and the Ministry of Education in Singapore. Hence, as is the case in the UK, Singaporean students follow national guidelines and learning outcomes which outline what should be contained within the science curriculum. However, no details are given on the methods for teaching the course and teachers have freedom to deliver it how they choose.

After 10 years of general education, all students go to tertiary education, either junior colleges (31% of students), polytechnics (43%) or ITE (Institute of Technical Education; 22%).

Academically inclined students take A-levels during this period and then proceed to university. Other students may take diploma courses in technical or business subjects at polytechnics. Students with GCE O- or N-levels can take skill-based certificates in technical or vocational subjects at ITE. Outstanding ITE graduates can also go on to polytechnics or universities. About 30% of students go on to university in Singapore where, notably, more than half the programmes are oriented towards science and technology. However, many students go abroad to study at university.

The well-structured education system in Singapore has been crafted in a short time frame but enjoys marked success. The People's Action Party (PAP), which has ruled Singapore since independence, is keen to direct funds into educational initiatives that will supply the manpower needs of specific industry groups, and promote continuous innovation. It has also thought carefully about the links between stakeholders that impact on schooling. Both policy coherence and implementation consistency are brought about by the very close tripartite relationship between the Governmental Ministry of Education, the National Institute of Education (NIE; the country's only educator training institution), and the schools. The ministry is responsible for policy development, while NIE conducts research and provides pre-service training to educators. Such research is fed back to the Ministry and is used to inform policy development. Since NIE professors are regularly involved in ministry discussions and decisions, it is relatively easy for NIE's work to be aligned with ministry policies. This tightly-coupled system has had the power to implement wholesale changes to the Singaporean education system. I was informed of two such initiatives that have had much success in recent years; first, *Thinking Schools, Learning Nation*, and second, *Teach Less, Learn More*.

1. **Thinking Schools, Learning Nation (1997)**. By tailoring education to the abilities and interests of students, with a degree of flexibility in subject choice and school specialism, this initiative prioritised the development of creative thinking skills and a lifelong passion for learning. Curricula and assessment changes put greater emphasis on project work and creative thinking, and resource commitments were focused on integrating information and communication technology (ICT) into classrooms, as an enabler of new kinds of self-directed and collaborative learning. Professional development, career paths and incentives

for teachers were also revamped and teacher education upgraded. "*We need a mountain range of excellence, not just one peak, to inspire all our young to find their passions and climb as far as they can*," explained Tharman Shanmugaratnam, then PAP Minister for Education (Lee *et al*., 2008).

2. **Teach Less, Learn More (2004)**. Despite the Singaporean education system's successes, learners were judged to be too passive; driven to perform, but not necessarily inspired. In a 2001 speech, the then Minister for Education, Teo Chee Hean stated that, '… *we [the Singapore government] recognise that mere knowledge is not enough. It is the ability to create and use new knowledge that is more crucial.*' The stage was set for a transfer from a predominantly knowledge transmission model to a system in which students engage in complex knowledge construction. While keen to maintain its strengths in literacy, mathematics and science, it was seen as necessary for Singapore to become less dependent on the '*rote and regurgitation*' model of didactic teaching and repetitive testing, in which pupils' engagement and diligent note-taking were considered more than just proxies of learning, and more on independent, discovery-based and self-directed learning in which the teacher takes on the role of a '*devil's advocate, facilitator and argument stirrer*' and '*pupils work harder than the teacher!*'

Both educational initiatives have been acknowledged as key components in recent successes in the Singapore's education system, not least in developing students' Scientific Literacy. Those with whom I spoke were keen to point out that no special efforts had been made by the Ministry of Education to prepare or prompt teachers or students for the PISA examinations; instead, the organisation of the education system, and much of the teaching pedagogy that will follow in this report, were responsible for the success enjoyed by the Republic. Hence I was inspired to focus in more general terms on the day-to-day practices adopted in the classrooms of the schools I visited.

With regard to the teachers themselves, I was informed that all in Singapore receive training in the curriculum at the National Institute of Education (NIE) at Nanyang Technological University. They take either a diploma or a degree course depending on their level of education at entry. There is a close working relationship between NIE and the schools, where all new teachers are mentored for the first few years. As NIE's primary purpose is training all Singapore teachers, there are no divisions between arts and sciences and education faculties. This, according to one of the Senior Leaders I spoke with, avoids some of the conflicting priorities that has been an issue for some British teacher education programmes. as course are more focused on general pedagogy. During a teacher's subsequent career in Singapore, talent is identified and nurtured, rather than being left to chance. After three years of teaching, teachers are assessed annually to see which of three career paths would best suit them – Master Teacher, Specialist in Curriculum or Research or School Leader. Teachers with potential as School Leaders are moved to middle management teams and receive training to prepare them for their new roles. Middle managers' performance is assessed for their potential to become Vice Principals, and later, Principals. Each stage involves a range of experience and training to prepare candidates for school leadership and innovation.

3.2. Teaching and Learning Strategies in the Classrooms of Singapore

'Consider yourself in the students' shoes at all times.'

Quote from a Principal at one of the visited schools.

In an survey I provided to students upon arriving at each school, I asked three simple questions: 'what is the purpose of learning science?' 'what things do you enjoy about learning science?' and 'what things do you not enjoy about learning science?' Representative phrases taken from the surveys are provided in the table below and are very insightful.

What is the purpose of science education?	What things do you enjoy about learning science?	What things do you not enjoy about learning science?
"*To innovate, invent and create*"	"*Finding out the reasons behind things*"	"*Memorisation*"
"*For the sake of the future*"	"*Seeing how things work*"	"*Facts*"
"*To help the world*"	"*Researching things*"	"*The textbook*"
"*For the pursuit of the truth*"	"*Venturing into the world of the unknown*"	"*Regurgitation*"
"*It helps us in our daily lives*"	"*Gaining a sense of satisfaction*"	"*Tests*"

A table to summarise a brief entrance survey undertaken by students in the four visited schools.

The results of these surveys provided me with prompts and ideas to follow up during my time in the schools, and will serve as a point of discussion later. My Fellowship predominantly involved immersing myself in the day-to-day events in the classrooms and science laboratories of four schools in Singapore. Much of the time I observed from afar, reflecting on the teaching and learning strategies that were employed. However, on occasion, I was able to talk at length to students and even get involved in the lessons myself. Conversations with teachers before and after their timetabled contact time with students was useful to clarify aspects of my observations.

A great number of activities I witnessed during my time in schools in Singapore are, I believe, transferrable by their nature to British classrooms, and are described in the following section with occasional examples of their use. The ultimate aim of this is to better develop students' knowledge and understanding of science in general, and Scientific Literacy in particular.

3.2.1. *Letting Go, So They Get Going*: Dialogue, Discussion and Debate

"***The one who does the talking does the learning.***"

Lev Vygotsky.

Acquiring an understanding of science, and Scientific Literacy, undoubtedly requires much more than simply memorising facts or reproducing experimental methods. Instead, students must build new understandings on what they already know, modifying their current conceptions when necessary, by engaging in some form of generative scientific inquiry into authentic questions. Furthermore, it is widely recognised that a student's ability to synthesise information, and make choices about one's own learning and to question ideas of others, is best enhanced vocally through discourse.

A common theme that emerged from my discussions with teachers during my time in Singapore was the widely-held belief that new knowledge acquired from 'traditional' transmission style teaching may not be well-integrated with students' prior knowledge. Echoing the intentions of the *Teach Less, Learn More* initiative, teachers described how, despite being fact-led, learning science is about constructing meaning for abstract ideas. Hence it does not follow that teaching science should be didactic. Indeed, abstract ideas cannot be 'transferred.' Instead, the learner constructs, rather than passively receives, meaning themselves from their experiences and social interaction. Effectively, teachers were well-versed in the premise of

constructivist education. However, this was not rhetoric; I was able to see a great deal of student-centred meaning-making during my time in the Singaporean classrooms. Teachers were committed to arranging their classrooms around tasks that brought students into contact with new knowledge, skills and ideas. It was in such contexts, many of the teachers argued, that so-called ***cognitive conflict*** would most likely occur, namely the tasks cause students to question their assumptions and then adjust their beliefs. Indeed, I was inspired to hear that science teaching in Singapore was geared towards ***addressing misconceptions***. These are rife among students and much of science education is derailed by misunderstandings that frustrate students and hold students back. Good examples include the idea that air exists between particles, mass is equal to weight, and the confusion regarding measures such as precision, accuracy, reliability, validity, and so on. However, it is widely recognised that correcting such misconceptions can be a powerful teaching tool. For example, listen for the cogs turning when you ask a student to consider why, in the film *Titanic*, Rose survived the cold but Jack didn't, despite the water he was floating in being warmer than the air surrounding her!

Constructivist teaching aiming to provoke cognitive conflict was a genuine aim of the teachers to whom I spoke. Many promoted this using a pedagogical style called ***dialogic teaching***. This prioritises the medium of talk between students and the teacher during classroom activities, and also between students. That scientists rarely work alone underlines the importance of this technique; the key skills of communication and sharing, defending and challenging ideas help students to reflect on their learning. Teachers were also keen to employ in their practice the well-recognised concept of the ***zone of proximal development***; they recognised that all learners require the support of a more competent other, be it teacher or peer, to 'scaffold' their learning. Lesson plans were hence well-pitched in which the challenge level ensured little boredom or frustration, and often prompted rich dialogue between students in which they were able to vocalise their ideas and consider those of others, with immediate and measurable learning gains.

How best to promote dialogic teaching in British schools has been a key question in recent years. Unlike many other curriculum subjects, which lend themselves to debate and argument, much of the scientific curriculum is focused on building a body of core knowledge.

Purposeful group work in Singapore appeared to me to be intrinsic to teaching; unlike the situation in many British classrooms, group work was seen as consequential and teachers were not fearful about loss of control or pressure to deliver the curriculum.

1. Strategies for promoting ***brief periods of group work*** were very common in the lessons I observed. ***Think-pair-share*** was a technique I saw on a number of occasions. After the teacher had asked the class a question, or prompted individuals to brainstorm ideas on a topic, he or she would ask students to pause for individual consideration for at least ten seconds, then turn to a partner and through discussion arrive at a shared response. Once all hands had gone up to indicate readiness, students were chosen by the teacher to contribute to a wider class discussion. From discussion with students, it was clear that they appreciated the opportunity to 'test out' their ideas in 'student language' with a peer before submitting them on a wider stage. As far as the teacher was concerned, answers were more structured and well considered, possibly because the technique forced them to spend time considering their answer well and making connections between different ideas. I also observed another related technique, called ***best composite answer***, which was used to good effect with longer-answer questions in one class. This involved students answering a question on their own initially, then joining together with others to decide on a combined answer based on the best features of their individual submissions. This was particularly well utilised, on one occasion, using a team-based competition as a motivator: the answers submitted to a question on inheritance in birds were hugely impressive!

2. ***Longer periods of group work*** were less common in the lessons I observed. However, the techniques used to promote them were highly sophisticated. Of note, when groups came to present their work to the rest of the class, it was not the case at all that teachers insisted on repetitive, one-after-the-other PowerPoint presentations or posters, as is the case in many British classrooms. Novel modes of presentation were often employed, including the ***marketplace approach***, in which representatives stood by their work as others circulated, as well as other techniques to encourage ***active listening***. Moreover, in terms of feedback, ***responsibility for group work was shared*** and any constructive criticism from the teacher or other students was not directed at any particular member. For

example, the teacher insisted that all members of a group were upstanding when feedback was given.

a. In ***listening triads***, students worked in groups of 3 in which roles are assigned - talker (explains something), questioner (prompts & seeks clarification), recorder (makes notes and writes a report); the roles are then swapped and students address a section of a topic each. This was undertaken on a number of occasions in the lessons I observed and helped students in numerous cases to generate a set of notes on a topic through collaboration with peers.
b. ***Snowballing*** was another technique that I witnessed on a couple of occasions and this worked well to prompting students to compare ideas. Firstly, students work in a pair, which then joins together into fours. Then a spokesman for each group feeds back to the class; however, all members of the group are expected to join them and also offer their perspectives.
c. An alternative, which was observed in one group, was the ***envoy technique***. First, all groups engage in undertaking a similar task; then, one person from each group is selected to be an 'envoy' and move to a new group to explain and summarise their findings, but also to explain what the new group achieved. The envoy then returns to the original group and feeds back to their home team.

3. Methods for ***regrouping*** students were inspired and had as their premise the effective transfer of 'experts' around the room. They included ***rainbow grouping***, in which students given a colour or number as they work in original groups, only to be regrouped based on these differentiators such that the new groups consist of students from all previous groups. ***Jigsaw grouping*** was another, and involved dividing the group to work on subsections of a topic in 'home groups' to become experts; the experts then leave their home groups to join with other similar experts from others groups as they pool understanding. In both cases, the return of students to their 'home group' enabled the teacher to ensure that all students were exposed to the totality of the material.

4. More imaginative strategies for promoting dialogue included a technique I observed that was referred to by the teacher as an ***object circus.*** This involved students visiting different 'pods' in various parts of a room with their books to research or evaluate. This was particularly successful when younger students were tasked with finding out the ingredients of various sweets from their packaging, and with older students who circulated to assess their work using distributed mark schemes. A related technique, referred to as a ***carousel*** by the teacher who employed it, involved students visiting at range of 'stations' to undertake extended tasks; for example, a reading comprehension exercise using a printed text as a stimulus, a crossword, a piece of listening comprehension, an oral examination by the teacher, an interactive activity using a mini whiteboard, and so on. Both activities effectively broke up the lesson with periods of physical activity and helped in this respect to minimise boredom; in both cases, the final 10 minutes of the lesson were reserved for discussing the activities and arriving at a common set of goals to further revision. Finally, in ***maps from memory***, students in one class were provided with the opportunity to discuss a technique they intended to use in order to reproduce an image of the nitrogen cycle that one member would be shown by the teacher for a very short period of time. This inspired discussion beforehand (should students go up in rotation? should the same person go up each time? should the student with the best memory go up first or last?), but also during and afterwards, as students debated aspects of the image and associate scientific underpinnings.

5. I was fortunate to have been able to observe a couple of scientific debates during my time in Singapore. Such activities clearly aided the students in developing a wide variety of skills pertinent to becoming scientifically literate, including justifying their opinions and helping them to understand others' ideas in light of evidence. An example I witnessed concerned the evidence for and against the heliocentric view of the solar system. The first employed an ***alley debate*** in which the teacher walks slowly down two opposing lines of students (those 'for' and those 'against' on either side), and steps to either side if a student's argument convinces him or her. This was an effective technique and moreover enabled this teacher to differentiate the activity: he ensured that the more able students were towards the tail-end of the line, as the last speakers must come up with an original argu-

ment. In another debate I observed, involving the eldest students in the school, the teacher had planned a lesson involving ***Socratic circles*** and had asked students to prepare for the lesson in advance. The debate concerned the safety of genetically modified foods and students were given roles to play - effectively people's views to adopt - and had to argue for them convincingly. The technique centred about the division of students into two groups arranged in two concentric circles, in which the outer members were observers and the inner members were participants. Peer evaluation then takes place, followed by teacher comments, before members of the outer and inner roles are exchanged, and the process repeated.

In addition to the techniques described in detail above, I also observed a great number of other strategies which had been crafted by teachers in order to promote discussion, debate and dialogue. These include ***role-play***, in which students were tasked with acting out scientific concepts (memorable instances included Year 8 students modelling electrons in circuits and the components involved in protein synthesis in a Year 10 lesson). Finally, one teacher simply stated that she asks students to ***explain a topic to peer as if they were a younger student***; the premise in this regard being a famous quote of Einstein's: '*If you can't explain it simply, you don't understand it well enough!*'

Although not widely practiced and not observed, I was informed by some teachers of other techniques to promote dialogue that they have recently conceived or heard about on continuing professional development courses, and are keen to put into action in their classrooms:

1. ***Dragon's Den*** centres heavily on collaboration and competition, clearly-defined roles and clear assessment criteria. 'Entrepreneurs' pitch their idea hoping for 'investment,' using skills and factual information to convince by formulating a strong argument. The investors challenge, ask questions, draw conclusions and assess viability through rigorous assessment. Notably, the teacher who had described their use of this was keen to point out that it was particularly the gifted students who gained most from the investor roles, and providing them with prompt questions was sometimes necessary.

2. ***De Bono's Thinking Hats*** was used to structure six approaches to thinking in one teacher's classroom, particularly in problem-solving scenarios. Students were given hats, marked with different questioning approaches, and were tasked to probe another member of the class by approaching a problem from a different direction. This is linked with ***Philosophy for Children (P4C)***, whereby students are encouraged to ask and answer open questions around a theme or stimulus.
3. In ***numbered heads together*****,** the teacher would label each student 1 to 4 during a group task. When the teacher called out a given number, all students with that number would need to feed back on their group's work after a short period of notice. One teacher described to me how students see this approach as 'low risk' as they are contributing on behalf of the group as a whole.

Clearly, the Singaporean class activities I observed were very much geared towards the promotion of dialogue and collaboration. Moreover, teachers were expert in coordinating this and had 'ironed out' some of the more common problems encountered when using group work, which are often cited by British teachers. Approaches to more effectively monitor and control the pace of independent work were in place the planning stage. These include distributing roles in the group to improve efficiency of working, employing systematic 'checkpoints,' including asking the groups to reveal their progress at each ten minute interval, and hosting a 'clinic' at the front of the room for personalised help, such that no group is waiting for the teacher to provide them with guidance to allow them to move forward. By paying close attention to group composition and by giving roles to group members, in one case with paper-based 'job descriptions' of the questioner, scribe, coach, and so on, teachers were also well-versed in dealing with issues of dominance of reluctance in groups as they undertook tasks. During all group tasks, teachers were freed up to benefit from the opportunities to monitor all students' progress and refocus individuals as necessary.

Another very common technique that was used by teachers in Singapore to promote dialogue, but on a more personal and specific basis, was the use of peer assessment. This is of particular note for British teachers. The recent Ofsted report found that, despite students in the U.K. increasingly becoming '*instructional resources for one another*,' the approach is not universally established and students in some classes have not been trained effectively enough in assessing their own and others' work. For example, without effective training, students tended to praise the quality of presentation, rather than the depth of understanding of science concepts that they were assessing, among other issues.

In discussions with teachers regarding peer assessment, I was informed that many ask themselves if they have conformed to three requirements. First, have they set up a supportive classroom climate so feedback is constructive? Second, do the students know and understand the success criteria? Finally, have they modelled effective peer feedback to illustrate how to discuss and critique each other's work? The teachers described how they did not have to work too hard to establish the first and second requirements. In their classrooms a climate of trust had been build over many months and some had established a 'collaboration contract' with their groups to promote the values of respect and professionalism during such activities, centred around the premise, '*how would you like to receive the feedback you are giving?*' The use of exemplar pieces of work, of a range of qualities, was also useful to explicitly illustrate what makes a good submission. It was, it appears, solely a case of improving the criticality of students' dialogue which was cited as being a barrier to effective peer assessment.

To this end, many teachers described how they had employed techniques such as ***two stars and a wish*** and ***sandwich-style feedback*** to prompt students into making constructive feedback by 'sugar-coating' points of development. Supplemented with modelling using role-play, as well as listing half-sentence prompts to encourage critical comments on the board (such as '*I would have liked to hear more about…*' '*This would be better if…*' and '*One thing I would change about your work is…*'), from which students can choose. Another option was to provide a feedback form that other teachers might complete, containing tick boxes for issues relating to presentation (to emphasise that these aspects are not overly important) and open spaces for extended comments that relate to the content of the presenter's work. Teachers described how such approaches had limited bland peer feedback focusing on aspects of presentation and layout and fosters a greater degree of criticality in feedback.

Finally, related to the promotion of dialogue in class, an important part of provision in the schools I visited was ***peer-to-peer mentoring*** *outside* of lessons. Singaporean teachers informed me of how mentored students make significant educational gains; this chimes with my observations in my own school. *Mentorships* are advertised to older students and resources are provided to them once they 'secure' their post. I am aware that research is being undertaken at various education faculties in the U.K. and Singapore to find out the mechanism of these gains; however, it is fair to suggest that the progress made by students in this comfortable, supportive atmosphere, in the company of a student who very recently faced similar challenges, is a major contributing factor. It is of note that the contributing older student has much to gain too from this symbiotic relationship. In my conversations with them, several told me that they had developed their ability to describe and explain and this has helped them at interviews and in crystallising their subject choices.

3.2.2. *Maintaining Curiosity*: Inspirational Activities

'***Physicians take an oath that commits them to 'first do no harm'. The best science teachers… set out to 'first maintain curiosity' in their students.***'

Ofsted Report, *Maintaining Curiosity: Science Education in Schools*, November 2013.

As described in a recent report by Ofsted, in practice it is not the course specification, but the effectiveness of the teaching that engages students. In the best lessons observed by inspectors, '*the teachers made the course content come alive and pushed learning well beyond the specifications.*' Yet as one British student said in their report, '*I do not see how the practical activity is supposed to link to the science we are doing, and I cannot see what use that science has*.' The feeling of the inspectors was that this view was more than commonplace.

As described earlier in this report, great emphasis is placed in Singapore on education as a driver of future economic prosperity. Hence it is hard to imagine that teachers should find the time, let alone be inclined, to place an emphasis on making lessons fun and interesting. Yet what I saw somewhat surprised me: a desire to promote enthusiasm, and a love of learning,

was a key feature of the lessons. '*How can you expect a student to learn,*' one teacher claimed, '*if they are not motivated*?' In contrast to aspects of the aforementioned Ofsted report, in the best practice I saw in Singapore, teachers asked students what they would like to find out about a topic and then used the responses to shape a sequence of lessons. They explained the connection between the science in the lesson and the bigger learning journey; in effect, material was routinely presented to the students in ways in which the theory was connected to the child's world and their experiences. In the best example of this, a teacher put the students into the position of scientists who had made discoveries in the past. By 'discovering' concepts for themselves, students shared the experience of the pioneers and hence heightened levels of intrinsic motivation in their students, who were happy to learn for the sake of learning. Accordingly, the level of student engagement in the classroom remained high and, in contrast to the British system it seems, had a part to play in the high levels of uptake of science in later education and in the workplace.
Many of the techniques employed by teachers in Singapore to sustain interest, enthusiasm and curiosity were, broadly speaking, not new to me. Nonetheless, they were used in such a way that students were motivated during their long days of learning. Many were undertaken in pairs or in groups - dialogical teaching permeate aspects of some lessons - and could be translated into classrooms of most school subjects.

Transferrable **starter activities** were common and used very effectively. These 'hooked' students at the start of the lesson and captured their interest in a new topic, priming them for subsequent learning. Well done, students wanted to know more and also generated a climate of involvement and contribution. These ranged from the more overt, including an activity referred to as the ***entrance ticket***, in which students were expected to answer a pre-prepared question on the board, to those that were more subtle. They could loosely be grouped into two themes:

1. **Involving students in word and concept games**. These included ***where's the answer?*** in which students were provided with a card with an answer as they enter the room; the teacher went on to ask a number of questions to which students needed to identify themselves. ***What's the story?*** was used with higher-ability classes in which students were

provided with 5-10 words that needed to be combined into a short paragraph of continuous prose. This was used particularly well by a teacher as he introduced the carbon cycle: he had pre-selected key words necessary to explain the process (e.g. photosynthesis, decomposition, deforestation, etc.) and after the activity was able to quickly scan through students' answers to gauge an opinion of their current level of understanding. In ***what's the question?*** students were provided with an answer and then tasked with discussing the possible question(s). This was used effectively with the words 'photosynthesis,' 'light' and 'glucose,' to which students' 'question answers' were very well crafted. Another, called ***put it back together again***, required students working together to put text, broken up into an illogical order by the teacher, back into its original order. Finally, ***What's the picture?*** involved students partaking in an activity reminiscent of TV's *Catchphrase*, in which tiles were removed that were blocking an image, while in ***odd one out***, students were provided with vocabulary and asked to find the anomaly. This was well achieved by one teacher and relied heavily on the careful selection of words to prompt thinking and probe understanding (e.g. xylem, phloem, stomata).

2. **Provoking thought and/ or engaging students emotionally**. Making a ***controversial statement*** (for example, '*all molecules are compounds*,' '*the eye is just a biological camera*' or '*DNA polymerase is more important than RNA polymerase*') or revealing an amazing fact ('*there is over a metre of DNA in each of your cells!*') can encourage involvement and debate. Related to this, another teacher referred ***'wicked' questioning***, which involves asking questions which have no obvious answer but can be used to capture interest and stimulate discussion - e.g. '*if you had chlorophyll in your skin, could you photosynthesise?*' and '*how do you know the person next to you is alive?*' Similarly, one teacher revealed his secrets to 'hooking' students at the start of the lesson, which invariably involved teaching for dramatic effect: '*I wasn't going to tell you this, but…*' '*I bet you've always wanted to know this…*' and '*I bet this is a question that must keep you awake at night!*' Several teachers spoke of the danger in many science lessons, partly because of the nature of the subject, of students becoming 'too willing' to accept ideas. Many had started using techniques such as ***devil's advocate***, in which they took on the role of a cynic and challenged the learners to argue against their way of thinking in an attempt to convince them otherwise. Similarly, hosting a ***mock trial***, complete with pros-

ecution, defence and judge, had similar outcomes with other classes, I was told. Planned opportunities for humour, the use of 'slang' and 'student speak' in appropriate measure, stories and ***using the teacher's own experiences*** were also used effectively in at many cases. On one occasion, the teacher referred to a recent story in the media regarding the recent Ebola outbreak to hook students into the lesson. On another occasion, in discussing co-dominant inheritance, the teacher described how, as a child, he would play with snapdragon flowers that grew in his grandparents' garden. The students were hooked by the insight into the teacher's childhood! Finally, many teachers told me how they regularly relate tasks to people - whether they be last year's cohort of students, the 'top set', or even themselves when they were students. The positive effect of this, I was informed, was that suggestions more likely to be taken on board by students if suggested by others in their shoes.

Transferrable **plenary activities** were common and used very effectively. These provided an opportunity for the teacher to gauge the students' learning, to aid subsequent lesson planning, and for the students to review their experiences at the end of the lesson. Once again, these could be overt and ranged from those that focused on summarising the material covered, including ***hot seating*** a student to provide an ***end-of-lesson review***, to those that had a metacognitive slant, such as ***learning triangles***, in which students used a diagram of one downward-facing triangle inside a bigger upward-facing triangle as a format to list three things they learned and one thing they didn't grasp. In the latter case, the teacher was given the valuable opportunity to be seen to act on students' feedback: in the starter or at the beginning of the next lesson, a quick summary of their thoughts could be given, with reflections on how it is being addressed. More subtle strategies included:

1. ***Dominoes/ 'concept loop'***: each student is given a piece of paper on which a question and an answer is written above and below each other. One student reads out the question and the student with the answer responds, then calls out their question. The cycle continues.
2. ***Spot the errors***: students enjoy looking for and identifying mistakes on an unmarked 'exemplar' script or piece of extended writing - especially if provided with a red pen!

3. ***Giving students choice***: to increase autonomy, ownership, motivation and responsibility, one teacher spoke very highly of the practice of providing students with the opportunity to choose which task to undertake - e.g. written task A or B for homework, or answer 3 of the following 5 questions.
4. ***Using authentic texts***: including newspapers, magazine articles, and books from the library, this pursuit puts students' learning into a real-world context. It also provides more overt opportunities to link with the concept of Scientific Literacy, as students could be asked to weigh up claims and counterclaims in the media or in advertisements and packaging. Forging links between the department and external associations was commonplace in Singapore, as will be discussed later, and this provided a wealth of primary materials on a whole host of subjects for pupils to use in class. Students were challenged to bring in their own interests and refer to their own experiences.
5. ***Opportunities for creative writing***: examples such as 'the journey of a ham and cheese sandwich' are common in British schools; however, the impression I gained in the Singaporean system was that such pursuits were often hugely imaginative and often inspired by students' ideas themselves. In one example, students are asked to design, draw and annotate a creature given its habitat; similarly, other students imagined they are writing a descriptive letter 'home' from a planet in another solar system with a longer solar orbit and terrestrial rotation time. Such pursuits sometimes provided the opportunity for cross-curricular linkage. For example, one teacher described how she had set a task in which students were to investigate the lesser-known evolutionary biologist Alfred Russell Wallace; another, the contributions of the now-discredited cold fusion scientists to our understanding of scientific rigour. Combining historical and social aspects of education with the scientific material was a key focus, and despite the theoretical nature of the lesson, students' interest had been captured and they could understand why that particular process has made such an impact on modern science and on world history.
6. ***Inspiring healthy competition through team games***: a huge variety of games had been adapted by Singaporean teachers for use in the conclusions of lessons, including ***Dingbats, Blockbusters*** and ***Pictionary***. One group had gone further and had designed and commissioned a board game based on monopoly to help students learn cell ultrastructure.

7. ***Videos***, which have for long had a somewhat bad reputation in schooling as a teaching and learning pursuit, were used very effectively in the lessons I witnessed. They were stopped and started in chunks, and used as a basis for discussion, and this acted as a very powerful stimulus for discussion: it is amazing how a video clip instantly engages students!

In Singapore, the place of technology in the classroom was enshrined early on, by the *Thinking Schools, Learning Nation* initiative. Singaporean students are akin to their British counterparts in that they are so-called 'digital natives:' they regularly interact with technology and seek implementation of it in all areas of their life. The teachers I observed did not shy away from using technology in the classroom; on the contrary, they sought new ways and means to engage with their students through its use. Lessons using tablets, laptops and other digital equipment were common. I observed a number of notable uses of technology worthy of mention here, including the widespread use of ***QR codes***, which are easy to print and were used to provide subtle differentiation as links can be scanned on students' books to direct them to differentiated resources, the use of computer apps such as ***Plicker, Socrative and Kahoot*** to facilitate class polling in response to multiple-choice questions, and the use of ***word clouds*** to help with learning key vocabulary. Also common was the use of virtual laboratory programs and other sources of e-learning, for which students often had remote access at home. The use of crosswords, which is more commonplace in British schools, was also seen - but teachers were well-versed in constructing their own, using various online programs.

One common practice caught my eye in particular; the use of ***visualisers***. Teachers used these to show how they would answer examination questions in 'real time' and even demonstrated 'live marking' of scripts as students followed. Through such an activity, the teachers were very powerfully able to model how to draw diagrams, plot graphs, and so on. In one notable case, a teacher of students in the oldest year group were shown how the teacher converted a complicated molecular process into a series of cartoon characters that interacted with each other on the page via a flip-book style production. It enabled students to not only see 'how it is done,' but also the more subtle thought processes, shaping and modifications involved (including mistakes!). For example, during a lesson on refraction for Year 8 students, one teacher showed a variety of responses of students from a previous year that illustrated common errors made by students and how marks had been lost when drawing ray diagrams. Through activities that reveal where errors are commonly made, many teachers were keen to impress on me that students avoid making them in their own work.

One final point. The positive relationship between teachers and students was one factor that struck me during my visits; it is widely regarded that this can have a significant effect on the attitudes of learners. In all classes I did not observe an overly firm or forceful mode of class control; instead it was a pleasant an atmosphere of mutual respect that appeared to underpin the calm, productive culture. There was very little of the low-level disruption and lack of concentration found commonly in British classrooms, as reported recently in many recent media reports. Speculatively, this is likely to be due to the attention teachers pay to maintaining enthusiasm and curiosity among their charged; boredom due to insufficient pace or challenge in the classroom is rarely an issue. All teachers routinely engaged in a 'meet and greet' at their classroom doors (with one foot out and one foot in!), they knew students' names and personalities, and were well versed in the intricacies of behaviour management: they had thought well about seating plans and the positioning of the most and least able; they gave thought to how they moved around the room; they made subtle comments and struck poses themselves that modelled how they wanted their students to act; and they '*caught them being good*' with well-meant praise to condition students to repeat behaviours or efforts. One striking policy which had been promoted in one school was that teachers should aim to end a lesson in a thought-provoking way, using questions, cliffhangers or surprises. This was summed up neatly by one teacher: '*don't end the lesson plan with a '.'; instead, try ending with a '…' '?' or even a '!'*'

3.2.3. *Catering for All*: Differentiation

"***If one thing is good for everything it is good for nothing.***"

Estonian teacher quoted in the report of Dr. Neil McIntyre, Churchill Fellow (2014).

In the recent Ofsted report, in a third of the science lessons observed by inspectors in British schools, the activities provided for some did not match their learning needs well enough to ensure that they made good progress. In practice, the widespread 'differentiation by outcome' approach was used in British science classrooms. The authors argued that it would make a significant difference to raising expectations if teachers assigned all students to the most challenging tasks from the outset, before adjusting them if they turned out to be too demanding.

Despite the presence of subject-specific banding in the Singaporean schools I visited, it was obvious through discussion with teachers that the practice of 'labelling' students, which is common in the British system, was greatly restricted. Implicit ideas of fixed ability or differential rates of progress were secondary to a general feeling that students were largely 'capable of anything' and it was just a means of 'unlocking their potential.' The rationale for this standpoint appeared to be a fear that the 'bar would be set too low.' As one teacher put it, '*when we ask "why hasn't this student grasped this concept yet?'" we should not answer "because they are a Grade C student," but instead "because I haven't presented it to her/him in the right way yet."*' I also sensed that, while a British teacher may be inclined to push a given student to aim for one grade above, it was more often the case with the Singaporean teacher that students were inspired to aim to reach higher. That there is flexibility in the banding system - students can transfer streams in light of unexpected academic outcomes - is perhaps one reason that teachers must continue to cater for all.

Indeed, ***motivating*** all students to better themselves was a key theme in the lessons I observed, and more widely in the ethos of the schools I visited. Inspirational quotes adorned the walls, and slogans such as '*find your edge in life*' were the schools' tag lines, but this ethos permeated into classrooms, with teachers using positive, motivational language ('*you can do this!*' and '*don't give up!*' were very common examples). I certainly sense that learners were being actively encouraged to realise that through a combination of effort, support, hard work, challenge and motivation, they can become more able and overcome obstacles to their learning. ***Putting learning into context*** was a strong feature of day-to-day life in the schools I visited. Displays of recently-graduated students and their destinations, with quotes from the students, were also common in corridors, as were newspaper articles and job descriptions to focus students on the rationale for their learning. Visits to external institutions and the welcoming of academics and experts to host masterclasses were common, too. Motivation comes in many guises and there were many more subtle means by which I felt it had been developed in many of the classes I observed, including a real commitment to ***student voice***. Often paid lip service by British schools, some teachers regularly asked students for their thoughts through 'postboxes' in their classrooms or an online survey forum. In such cases, the emphasis was very much placed on good practice and generated a culture in which students know their opinions are being sought and make a real impact.

Despite the large class sizes - many of the science classes I observed had more than 35 students - teachers were keen to personalise their lessons as far as possible. One teacher told me how she finds time each semester to sit next to a student during a whole-class activity for a one-on-one discussion. She described that, in many ways, this act was symbolic: the student sees the teacher's role as a partnership. She also described how this appears to be more important with younger students and cited a concept called the '*irony of dependency*:' students grow increasingly dependent on their teacher during the final years in school when assessment stakes are higher, but when they should be reducing their dependency on others. Another made a point of phoning home each week to speak to the parents of 2-3 students, to offer some congratulations and further guidance on a piece of work. What links these, and other, pursuits is an underlying sense that the teacher cares about the students, which has obvious positive effects on student motivation.

Despite efforts of push students to achieve, diversity in ability was welcomed in the Singaporean classrooms I visited. Language was rarely an issue - English was the medium of communication in all lessons I observed - but when it presented problems teachers were very quick to empower those who fell behind, using plain English, a visible and developing glossary, writing frames and visual cues. When questioned about the type of differentiation incorporated into their lessons in other respects, '*extension, enrichment and acceleration*' was cited by one teacher; '*stretch and support*' by others. They were conscious of the need to account for students of a ride range of academic ability, from those who require regular, consistent extra help to those, defined as 'gifted and talented.' It was obvious that paying attention to varying the depth, breadth and pace of learning was part of teachers' day-to-day practice in

Singapore, more perhaps than I have observed in the U.K. and elsewhere. The variety of differentiation means and methods I witnessed was enormous and ranged from so-called differentiation *by content,* in which teachers offered more than one version of material on the same topic, *by process* (giving some students more 'scaffolding' or guidance than others, either directly in person or some with extra support through writing frames), or by outcome (students are given the same task, but which offers the possibility of stretch to the most able but still offers challenge to the weaker completing it at a lower level). In one notable example of a lesson defined by sophisticated differentiation by process, in a Year 9 Chemistry lesson on the topic of covalent bonding, students were required to sketch the organisation of electrons in non-metal compounds. Several of the students picked up the topic easily and were keen to try harder examples, which they completed with similar ease. Rather than provide another list of covalent compounds, the teacher asked them to consider the arrangement of electrons in carbon monoxide, whose atoms are joined by a so-called dative covalent bond. This approach encouraged the most-able to adapt their knowledge to formulate a theory (using the higher processes of evaluation, synthesis and analysis) to predict the nature of the bond and the discussion afterwards provided the opportunity for them to evaluate their answer. In another example I witnessed in a sister group, which was studying the chemical reactions of marble, the teacher employed the 'all/most/some' approach in her lesson plan and incorporated this scheme into the displayed lesson objectives at the start of the lesson. In this case, the teacher stated that all students would be able to define thermal decomposition, most would be able to write the word equation for the thermal decomposition of marble and some would be able to translate this into a symbol equation. This strategy increased motivation of all students to strive to reach the teacher's highest expectations and keep up with their peers.

Another facet of differentiation, although increasingly disregarded in today's British schools, is the concept of ***VAK, or 'visual, auditory or kinaesthetic,' learning preferences***. The Singaporean teachers I spoke to about this were equally dubious about the idea that any given learner 'prefers' one style over another; however, they did cite is as a reminder to them to incorporate sensory variety into lessons. As an example of this, in one Year 7 chemistry lesson on particle theory, a teacher incorporated into a lesson a range of video clips, a fast-paced question and answer session and an activity in which a group of volunteers mimicked the movement of particles to the rest of the class.

There were a wealth of techniques that I observed that certainly fulfilled the requirements to be classed as sophisticated 'formative assessment' measures, which teachers in the U.K. have come to know as '*using evidence of learning to adapt lessons in real time in order to meet students' learning needs*'. As is the case in many British schools, so-called ***all-student response systems*** were very common in the lessons I observed in Singapore. These had a common, fundamental aim: to provide the teacher very swiftly with a gauge of understanding within the classroom, such that they could modify the lesson trajectory in response, and identify those for whom extra support (or stretch) was required. Examples included the widespread use of ***mini-whiteboards*** and ***ABCD cards***. In addition, one very widely used technique I observed, from which I feel classes in the U.K. could benefit, was ***hinge questioning***. These were described to me as '*mini plenaries*' in that they can help with breaking up the learning and to ensure that misconceptions don't last the entire lesson. These are based on just one important concept that is critical for students to understand before the lesson moves on and occur around half way through the lesson. It is phrased such that all students can answer it quickly and simultaneously and takes under a minute to answer. The lesson then goes on in one of two ways dependent on student understanding, as revealed by their responses. One example that I observed to good effect was as follows:

"*John put a glass of ice-cold water outside on a warm day. Droplets soon formed on the outside of the glass – why did this happen?*
(A) *Air molecules near the cold glass condensed to form droplets of liquid;*
(B) *Water vapour in the air near the cold glass condensed to form droplets of liquid water;*
(C) *Water soaked through tiny holes in the glass to form droplets of water outside the glass;*
(D) *The cold glass causes oxygen in the air to turn into water."*

This was used in a lesson involving the condensation of vapours into liquids, where the critical point was that students understand the process of water vapour in the air condensing onto cooler surfaces. The teacher collected responses with cards designated A, B, C or D and the student responses informed him as to which way to proceed with the lesson, namely whether or not students were ready to begin lab work or whether, as it transpired, he ought to discuss how to set up and carry out a simple experiment that would rule out incorrect responses.

3.2.4. *Bringing it All Together*: Helping Students Revise

"***More important for our students than their revision is for them to know what they need to know: it is important that students 'vise' before they 'revise!'***"

Teacher in one of the visited schools.

Perhaps more than in any other respect, the teachers in Singapore, compared to those I have observed in the U.K. and elsewhere, were more imaginative and skilled in conveying and guiding their students to undertake revision. They have developed and inspired students to become motivated to undertake this otherwise dull activity, both in class and at home.

First and foremost, students in Singapore have the clear notion that the purpose of the activity is to impose their own shape and order on the encountered material, to come to understand links, connections and relationships between aspects. This sound obvious, but in many cases a student's failure in an examination is due to an inability to recognise, at best, what to revise, and, at worst, how to go about it. In my discussions with Singaporean students, it was clear that all understood that ***effective revision is an active process***. Memories are made by doing things. As such, many students made themselves explicitly aware of 'grabbing their own attention' before they cognitively encoded something, and to this end used tried-and-tested mind-pegging techniques to memorise facts and 'hook' ideas. I was overwhelmed by the quality and quantity of strategies they employed in their own time: post-it notes were placed in strategic places, mind maps and pictures were drawn, story boards and diagrams were constructed, analogies were invented, notes were imaginatively retyped or audio-recorded, among others.

Activities in class that I observed ranged from traditional mind maps and pictures, story boards and diagrams, clever memorising approaches (way beyond the 'ROYGBIV' I learnt at school), to more traditional, individual modes of revision. Timelines and flow-charts (for sequential events such as the reflex arc), tables or Venn diagrams (for relationships between variables, similarities and differences), tree diagrams and mind maps (to compress a mass of material onto a single page) were all demonstrated by teachers, whose modelling empowered those students for whom the material can appear overwhelming to 'give it a go.' Other activities, which hinged more on classroom collaboration and activity and so permitted the teacher to take on a more circulatory role, included:

1. ***Bingo***: students are handed a 3x3 grid each and select 9 words from 20-30 shown on the PowerPoint. Some questions are called out, for which the words are the answers; the student calls 'full house' when he/ she has filled their squares.
2. ***Taboo***: students are challenged to describe a concept without using key words. I saw a particularly entertaining example of this with *peristalsis* as the key word (muscle, intestines and contract were not allowed!).
3. ***Missing word exercises and crosswords***, created by computer programs such as *Armoured Penguin*. In one case I witnessed a teacher *designing* a crossword using students' guidance: they were challenged to write a clear and precise definition for a given word, which can be identified by others without mistaking it for another.
4. ***Word mats***: to prepare for longer-answer questions, students were provided with an A3 paper in the middle of which an A4-sized blank space was left. Around this students were tasked to write notes (key words, statistics, etc.) to help them revise a topic and plan before they write.
5. ***Just a Minute***: the teacher writes a series of topics on the board; students take it in turns to stand up and talk about the topic for only 1 minute with no pauses, repetition, going off topic, slowing down, and so on.
6. ***Reversed objective***: after showing students an excellent piece of work, they are asked to list what they believe makes it of this quality by scrutinising and dismantling it. This essentially produces a model which students can use to recreate a piece of work of their own of similar quality.

7. ***Speed Dating***: the premise here is that a good way for students to remember what they have learned is to immediately use the learning to teach someone else. Chairs are placed in two rings, with students facing each other; the previous lesson, each student would have been given a topic to revise. This activity was hosted expertly in one class I observed as each student, provided with a register of the class, moved along their row and recorded whether or not the student in front of them succeeded in getting the answer right. Results are used by the teacher to inform planning and targeted tuition.
8. ***Ranking Answers***: involves students sorting five exemplar answers in rank order to gain a sense of what the examiner is looking for, and for even the highest achieving students to recognise what is required for the top grades.

3.2.5. *Feeding Back to Feed Forward*: The Return of Homework

"***Unless we provide guidance to students in our feedback, they won't improve. It's like a doctor offering a diagnosis without subsequent treatment.***"

Teacher in one of the visited schools, in a quote reminiscent of the AfL framework.

As reported by the inspectors in the recent Ofsted report, work set for homework was commonly insufficient in British classrooms in enabling students to reveal their understanding of a scientific concept or idea. The report also found that perfunctory marking is common in British secondary science classrooms. At best, this was little more than comments about underlining titles and using pencils for diagrams; at worst, it was so uncritical that incorrect work was ticked and praised, suggesting that the teacher had not read it. When marks were awarded, they were unaccompanied by any meaningful advice about how to improve. It was common for students to take a glance at their score, compare it briefly with their neighbours, and move on.

While science textbooks and worksheets were common homework tools used in the science classrooms of Singapore, they were invariably framed in a stimulating, engaging and contextual way. Often they took the form of longer written activities, sometimes taking several days, which allowed students to research, think about and then apply their understanding of a science idea through a summary explanation: indeed, the most effective practice took place where students had extended opportunities to explain, either orally or in writing, their understanding of the science behind the activities they were doing. Among a wide variety of tasks I witnessed, students were asked to write abstract for a given scientific journal, and others were charged with proposing solutions that mirror real-life scenarios (e.g. an oil spill and its effects). Nonetheless, when take-home student reports are formulated, I was informed that judgments were made on the totality of a students' work, including textbook work and exam results, but also contributions to lessons in discussion and practical activity.

Singaporean students were 'hungry' to know how they were doing; yet teachers were not confined to limiting their assessment to that *of* learning. This form of assessing students, sometimes called summative assessment, judges students' attainment against a formal and standardised set of criteria. It is what Ofsted found as being predominant in British schools. What was held more important by many of the teachers with whom I spoke was assessment *for* learning, also referred to as formative assessment, whose purpose is to guide improvement. I was inspired by the fact that in many of the classes I observed, informal tests at the start of the lesson based on oral questioning rather than paper were commonplace. This, in the main, was delivered using a ***random number generator*** to select students to answer, or by following a ***no-hands-up rule***, which encouraged the students read their notes and come prepared to lessons. In addition, when teachers provided feedback, they very often withheld the marks, citing research studies that suggest that providing feedback and a grade at the same time can cancel out some of the benefits of formative feedback as it distracts the student from the advice. Other techniques that teachers informed me that they adopt included ***plus/minus/equals***, which uses the last piece of work as a reference and so is linked to progress, and ***mastery marking***, in which a students' resilience and sustained effort is developed by handing back a piece of work as many times as necessary for the student to make corrections and bring it up to a top-grade standard.

That is not to say that Singaporean teachers do not entertain value-based assessment. On the contrary, much emphasis was also placed on assessment *of* learning, or summative assessment as it is otherwise known, by the teachers in Singapore. One referred to his intention to speak with his Head of Department about the possibility of administering to students a so-called ***'two-thirds-of-the-way' test*** which, in his opinion, would be the perfect marriage between summative and formative assessment. In such a scenario, he described, no mark would be given, merely comments to the student describing how they should better phrase or frame their answers next time. In this instance students should feel better prepared and able to attain higher outcomes: their 'mistakes' have been made in the period of build-up to the test and chances to improve have been taken.

In formative marking, work was handed back to the class, accompanied by teacher commentary relating to general mistakes and misconceptions, and this progressed into the provision of what some refer to as ***DIRT (directed improvement and reflection time)***. This necessary period of reflection is for students to work individually to respond to those personal requests from their teachers. At best this was achieved through a structured approach - perhaps a'faults and fixes' table, or by writing a letter to themselves in which they list the 'resolutions' they will follow next time they conduct a similar task. Some teachers gave students a supplementary task that led students to learn from their own errors. In the written feedback I was able to see (which, it must be noted, was offered less frequently but to a higher quality than that in typical British classrooms), teachers' comments were simple, diagnostic and instructional. It offered prompts as suggestions and achievable targets and, most importantly, questions to encourage further thinking and dialogue. In essence, a premise of 'read, reflect, respond' was observed in the Singaporean classrooms, and it was recognised by both teacher and student that good feedback between the two involves *dialogue*. the best written feedback is that which promotes further thinking. For example, in one Year 9 student's chemistry book I read constructive comments on student's practical reports into an investigation regarding rates of reaction. These included '*you have provided clear diagrams to explain how collision theory explains how concentration affects reaction rate – can you predict why an increase in temperature raises the rate of the reaction?*' and '*you have identified the anomalous results and comment on the accuracy of your experiment. What can you say about further work that* *could be carried out to validate your conclusions?*' Such extension questions prompted students to think about the work further and in more than one case I was informed by the teacher that the student had approached them with their response or had written a thoughtful answer beneath the question.

One notable, final point in relation to this section of the report is the feeling I sensed in Singaporean classrooms that 'mistakes are okay.' Students did not appear to be conscious of those around them when they asked questions, and were not in the slightest bit phased if they submitted a wrong answer. This is in contrast to the situation I have encountered in many schools in which students display 'peer fear' and are unwilling to take a risk. One teacher explained how it has become an ingrained part of the culture in the Singaporean school system; indeed, it is widely acknowledged that in order to learn, mistakes must be made. She refers her students to Einstein, who apparently reassured his charges that '*anyone who has not made a mistake has not tried anything new*.'

3.2.6. *The Teacher's Bread 'n' Butter*: Better Questioning in the Classroom

'***There is no such answer as 'don't know' in my classroom… students are always given the opportunity to think, make a measured guess or even 'phone a friend' by asking a peer.***'

Teacher in one of the visited schools.

I was challenged to question my own practice when I spoke with two principals about the purpose of questioning. The question really made me stop and think. We held a brief brainstorming session for five minutes and decided that the roles played by questioning range from regaining the focus of students, encouraging participation and discussion, to helping students see connections and identifying misconceptions. We agreed that the practice is one of the most important, yet often overlooked, components in the teacher's toolkit.

It was no surprise that many of the Singaporean teachers with whom I spoke ranked good questioning as a top priority in their practice. Many took the time to actually plan questions. In one case, I saw a lesson plan which, instead of objectives, was centred around a series of tightly-worded questions (a ***'question plan'***). By using expertly-crafted, pre-prepared questions as a 'cornerstone' of the lesson, the teacher was able to better demonstrate differentiation, progress and motivation. In another case, I witnessed a lesson in which a teacher had sophisticatedly woven into the lesson five ***'telegraph' questions*** about the cell membrane, which the students solved without realising it by the end. Most teachers had made it a standard part of their practice to display the ***'big' questions*** in a given lesson on the board throughout, such that the learner could direct all of his or her brainpower into answering, rather than remembering, the problems to be solved.

In general, however, teachers pursued similar strategies to those which are commonplace in the U.K. The so-called ***pose-pause-pounce-bounce*** technique was used to good effect on a number of occasions, in which the teacher gives students at least 3 seconds ('the miracle pause') to answer a question, after which the teacher 'bounces' to another student and follows the submission with a question to them (questions such as '*do you agree or disagree?*' '*how could his answer be more accurate?*' '*how would you explain X's answer to a younger student?*' '*can you add a little more?*' '*can you give me another example*' and '*what do you think of John's answer?*' were common in this regard). Another well-used technique that I saw that was used to good effect was to switch from ***closed ('fast-thinking')*** to ***open ('slow-thinking') questions***, namely, one that requires a short or yes/ no answer, to one that demands a response using more complex terminology and serious thought. Also noticeable during my time in lessons were little ***'tricks of the trade'*** used by teachers worldwide to help them cover all bases in a lesson. On numerous occasions I heard phases such as '*keep your hand up if you want to answer*' and the rhetorical question '*who hasn't said anything today?*' - a stimulus for the teacher to prepare themselves to seek out the quieter members of the group. Finally, questioning, by its very nature, can lead to lessons following different paths. Not least when it comes to unexpected student answers. On the occasions that a teacher was given an incorrect answer, I was inspired by the Singaporean teachers' responses. These included ***follow-up questions*** and further prompts, which both pressed the student to reconsider their submission, but also gave the teacher a better idea of the source of any misconception: '*How did you come to that answer?*' '*Who agrees?*' and '*That would be the answer to another question, but not quite this one - please try again*' were common statements in this respect.

Higher-order questioning was perhaps one of the most obvious ways in which teachers directly promoted thought processes through questioning that link with aspects of the Scientific Literacy agenda. By asking students to evaluate, justify and reason, teachers were able to direct students' thinking and hence promote relevant learning episodes. Questions seeking reasons and evidence: '*why do you think that?*' '*how do we know that?*' '*what are your reasons for?*' and '*can you justify your opinion?*' were combined with questions exploring alternative views: '*can you put that another way?*' and '*what if someone suggested that?*' In addition, questions that test consequences and probe deeper thinking, such as '*what follows from what you say?*' '*is there a general rule?*' and '*how could you test to see if that were true?*' were sometimes asked. Sometimes, however, questioning was highly contextual but nonetheless very sophisticated. In a Year 8 lesson regarding the role of chlorophyll in photosynthesis, students were asked to consider what would happen if a chemical was discovered that destroyed chlorophyll (this revealed far more of their conceptual understanding more than simply asking them to '*recite the equation for photosynthesis*'), while in another class the question, '*what happens at the particle level when mercury expands in a thermometer?*' gave more insight into their understanding than asking them to '*recall how the particles in solids and liquids differ in arrangement.*'

Some teachers referred to their use of the famous ***Bloom's Taxonomy*** to aid question planning to consider the level of challenge in questions. However, I was most inspired by one teacher, who referred to his use of an updated version, ***Anderson's Taxonomy***. This, she claimed, is better applied in science as it argues that knowledge is at the heart of each of these skills, rather than a cognitive level in its own right. Furthermore, knowledge drives the thinking at each stage: where the noun and verb intersect, command words (in italics) are selected to frame questions. This was effectively used in an older year group I witnessed, preparing for their upcoming examinations, who used the matrix in class to come to appreciate the level of difficulty demanded by different command words they were likely to encounter in the scripts.

The Knowledge Dimension	The Cognitive Process Dimension					
	Remember	**Understand**	**Apply**	**Analyse**	**Evaluate**	**Create**
Factual	*List*	*Summarise*	*Classify*	*Order*	*Rank*	*Combine*
Conceptual	*Describe*	*Interpret*	*Experiment*	*Explain*	*Assess*	*Plan*
Procedural	*Tabulate*	*Predict*	*Calculate*	*Differentiate*	*Conclude*	*Compose*
Meta-cognitive	*Use appropriately*	*Execute*	*Construct*	*Achieve*	*Action*	*Actualise*

The Anderson Matrix used by several teachers in lessons I observed in order to pose problems to students in line with examination command words.

3.2.7. Practical Work: *Both Hands-on and Minds-on*

'***Tell me and I'll forget, show me and I may remember, involve me and I'll understand.***'

Confucius.

There is a long tradition of practical work in British classrooms dating back to the nineteenth century. Its purposes are myriad, but the original rationales for its use still largely stands. It presents students with tangible, often strikingly visual, stimuli that may demand 'cognitive conflict;' it is a semi-autonomous activity gives students ownership of their learning; many students favour the discovery-led approach during practical work; and it acts as a conversational focus in group work to promote dialogue, which is sometimes a rarity in science lessons. In Singapore, too, it is held in high regard by both teachers and students, who are motivated to become able in using items of laboratory equipment. For instance, in one school I visited, students had to ***earn a licence*** (for items of equipment including the Bunsen Burner, microscopes and the burette) before they were able to employ it unsupervised.

However, despite the widespread support for the use of practical work in school among teachers, in a recent Ofsted report, many of them described the challenges they faced. Time in the laboratory was the most pressing concern. In the most extreme situations, any practical work that students did was the necessary minimum for controlled assessments. As a result, opportunities for illustrative and investigative scientific enquiry were limited. They achieved their GCSE grades but not the science practical skills they needed at the next stage. Indeed university staff and employers have for many years voiced concern over a lack of practical skill in students leaving school (for example, the Wellcome Trust report, *Life Study: Biology A-level in the 21st Century*, 2006). Even when it is employed in many British classrooms, the recent Ofsted Report describes how it is common for whole-class 'discussions' leading to a 'whole-class' experimental plan, students following a set of pre-prepared practical instructions (a recipe). Otherwise, results tables were provided in advance by the teacher, which denied students the chance to choose for themselves their system of recording. This echoes the findings of a major study by two British researchers in to the use of practical work in secondary classrooms, in which the strategy was found to be almost exclusively used to convey theories and opportunities were not taken to discuss scientific processes, and that teachers overwhelmingly considered a practical task successful if learners could merely enact the instructions and produce the desired observations, rather than grasp the underlying theory (Abrahams and Millar, 2008).

The key feature that struck me in observing practical work in Singapore was the supporting structures that gave each student, individually, the time and responsibility to think about the question or task, and independently design their own plan to solve it. In discussion with teachers, I was inspired to hear how they felt that empowering their students to make predictions and then investigate them with data is an important element of developing their scientific knowledge, understanding and literacy. Students experienced the scientific phenomena for themselves and then used that experience to raise their own further questions, thereby maintaining curiosity. The role of the teacher in this respect was to limit the scope of the options, actively supervised to ensure safety, and then steer students away from over-elaborate plans and spurious variables. Teacher commentary throughout the practical activity can also provide strong scaffolding to help them with this challenging activity, and to help students 'see' the phenomena in the way that the teacher ‘sees’ it, and to hint at the underlying theory and explanations. A term called ***guided enquiry*** was brought to my attention by one teacher. For example, in a practical that focused on friction, Year 7 students were given genuine freedom to design a practical to investigate the most effective way of reducing the force required to pull a wooden block along a lab bench - with some very insightful results - but along the way it was important for the teacher to reign in over-enthusiasm and correct misunderstandings that had the possibility of ‘snowballing.’ In conversation with the teacher afterwards, I heard how a great degree of time and effort had, however, been spent in developing students’ skills in this regard. For instance, one of the first activities all students in his class undertook when they started school was a discussion exercise in which the teacher asked students to design an investigation to find out how many drops of water will fit onto a Singaporean Dollar coin. This was complete with attention to accuracy, reliability, validity, and so on!

In the U.K. much has been made of attempts to help teachers guide their students during practical work. The *Practical Activity Analysis Inventory (PAAI)*, a framework for teachers to gauge the effectiveness of a practical task, was published by Robin Millar in 2009, and in part inspired the Government-funded CPD initiative in the U.K. called *Getting Practical*. In the observed Singaporean practical lessons there was evidence that teachers had given particular thought to the ways and means of helping students link what they saw with the theory that under[ins the phenomenon. Strategies included ***predict-observe-explain***, in which students predict what they would expect to happen and then explain what they see, and methods in which the teacher presents an outline of a ***model*** upon which students must elaborate, or an ***analogy*** to which observations can be related. I was inspired to hear that many teachers had taken it upon themselves to read around the subject in order to uncover further techniques to make practical work more ‘minds-on.’

One final point. Many practical activities in the Singaporean lessons I observed were undertaken by students on an ***individual basis*** **(Photo X).** This is in contrast to the common situation in British classrooms, as reported by Ofsted in its recent report, in which it is common practice for practical work to be done in pairs. There were limited opportunities to work independently in British schools, particularly to develop their individual manipulative skills in practical work, because teachers only required them to work in pairs or small groups. In other subjects with a practical basis, such as design technology or art, individual work is the norm. Although working in pairs may help to develop students' skills of teamwork and collaboration, it curtails personal initiative and independence, and can allow some students to avoid practical manipulations altogether. Working in pairs may be one reason why so many post-16 and post-18 students struggle with the demands of advanced science practical work in the U.K. when they have to do it by themselves.

3.2.8. Metacognition: *Learning How to Learn*

'***An effective teacher ultimately makes themselves redundant!***'

Teacher in one of the visited schools.

To make sense of our ever-changing world, some would argue that a key focus of learning is learning *how* to learn. Indeed, some express the importance for the sharpening, during schooling, of those skills which are associated with independent information seeking, synthesis and evaluation. Effective learning demands skills and strategies have to be learned in such a way that they can be transferred to fit new problems or situations not previously encountered. This has a clear link with the rationale of Scientific Literacy and are increasingly being identified explicitly as major goals of schooling.

It was notable in this regard that Singaporean teachers placed the promotion of 'thinking about thinking' high on their list of priorities in lesson planning. Questions in lessons such as '*which question(s) are you struggling with, and why?*' '*what one thing will you remember after this lesson, and why?*' '*how are you going to use today's learning?*' '*what evidence do we have to support that?*' '*how did you reach that conclusion?*' and '*how will you better tackle this problem next time?*' were very common in the lessons I observed and encouraged students to evaluate their learning and consider how they came up with the answer to a question. For instance, after giving time to students to predict and put into words how to make plastic from crude oil, one teacher approached the quick-finishers to ask how they arrived at their answer, which in many cases led to further discussion and enrichment of the topic. In discussion with students, it was clear that they benefited immensely from such approaches and many said that they had become more skilled at identifying the strategies that work best for them in addressing a similar, subsequent task.

Lesson techniques used in class by Singaporean teachers to aid their students in metacognitive activity were restricted to a small number, but each was very effective in its purpose.

1. The most widespread technique, which I refer to here as ***students as examiners***, was effective as it placed students at the heart of the assessment process by tasking them with the design of questions and an associated MS. Through such a technique, students were seen to develop their understanding of the success criteria that assessors use. For example, I observed Year 9 students to construct examination questions on the subject of evidence for evolution, namely continental drift, the fossil record and genetic analysis; they discussed their ideas with their neighbours before being asked to present their questions to the rest of the class for further critique. In students in examination years, this is extended to also focus on highlighted the creative worth of different components, the extent of coverage of the syllabus, the framing of questions and how the mark scheme awards the marks. Related to this, discussing success criteria, and showing exemplar work, was seen to raise motivation as students gained confidence and control over their learning. Indeed, some researchers have suggested that students respond well to a 'demystification' of the assessment process because it clarifies for the student what the teacher is looking for and underlines for them the best ways in which to improve and empowers them to correct themselves. One teacher I observed in this respect actually 'taught backwards,' for want of a better phrase, as they introduced a new topic with an examination question, which was systematically disassembled during the lesson. As a student in one of these classes clearly said, '*I finally figured that exams aren't scary - I learn much better now I know how I will be tested and because I can see exactly what exam questions are asking for.'*
2. Another pursuit that appeared to foster reflection on the students' part was a technique used by many teachers called ***flipping the classroom***. Largely driven by recent advances in technology at home, I was informed by many that teachers were increasingly giving notice to students of topics they will encounter in subsequent lessons, such that they come

prepared t and can start at a higher level and faster pace. These activities included watching videos, listening to a podcast, and so on. Apart from the obvious benefits - it allowed teachers more time to be spent with students and promote deeper learning and addressing misconceptions - many argued that it also prompted students to consider the structure of lessons and learning journeys for themselves, with associated cognitive gains.

3.3. Beyond the Singaporean Classroom

Although it is widely acknowledged that what transpires in the classroom makes the most signifiant difference to students' progress, it is without doubt that other aspects of school culture play their part in learning. In this section, I will reflect on discussions and observations I was able to undertake in the four schools with regard to three aspects of school life: extra-curricular activities, the role of the senior leadership team, and the role of heads of department.

3.3.1. The Role of Extra-Curricular Activities

'***Education is the kindling of a flame, not the filling of a vessel.***'

Socrates.

Although the involvement of students in clubs, societies and activities outside of school is common in many British schools, I received the impression in the visited schools in Singapore that even greater emphasis was placed on the 'development of well-rounded' students. In science, it is widely acknowledged that such pursuits complement learning by extending students' experiences with extra experiments, projects, and visits to external agencies where science is shown 'in action.' Most - if not all - extra-curricular activities related to Science are focused very much on preparing students for the challenges of the future. As described in one school's prospectus, '*these programmes will prepare our students to develop a scientific mind and attitude that will enable them to be adept citizens who care for the environment and have the technical knowledge and skills to contribute effectively to an increasingly technology-driven world.*' Furthermore, many teachers cited research in justifying the depth and breadth of provision, with the *Renzulli Enrichment Triad Model* being one memorable example.

Students were routinely offered the chance to meet professional scientists who explained their enthusiasm for science and gave students a sense of the breadth and depth of the subject. The government science agency A*STAR exposes students to research done by working scientists. Visits by academics from polytechnics and universities were also commonplace; one series of lectures on global warming and climate change, hosted by a local professor, proved particularly popular in recent times. In discussion with students, I was certainly left with the impression that they make huge personal and educational gains from such pursuits.

In addition to the societies and clubs that are relatively common in British schools, for example, *Science Society*, *Medical Society*, and so on, novel examples I encountered during my time in Singapore included:

- ***Innovation and enterprise clubs***, which provide opportunities for inquiry-based learning hands-on activities,. They involved individuals or teams of students undertaking thought and practical activities in order to generate novel remedies to posed problems. In many cases, these had an environmental slant: as part of this society, students collaborated in groups to design and construct structures using recycled materials to grow common Singaporean vegetables in vertical structures; another to purify water using an innovative strategy. The premise was inspired by the fact that the small island Republic has very little farmland and no fresh water supply and must depend on its neighbouring countries for many of its resources. Many students are annually able to present their work at the *Singapore Science and Engineering Fair*. Several of the projects I encountered were hugely impressive; for example, a robotic hand to aid tetraplegic patients and a literature review into a new material related to carbon nanotubes! One group had achieved some corporate success with their invention, *Ziptachable*, which was an innovative zip made of plastic and nylon that can be attached to earphone cords.
- ***Robotics clubs*** were very popular in the schools I visited. From my observations, however, it appears that the premise of these is not merely limited to the design and synthesis of robots *per se*. Instead, the pursuit acts as a vehicle to promote teamwork, creativity and problem-solving skills. This was a nationwide pursuit, I was told; several of the schools competed in the country's *National Robotics Games*.
- ***Research science societies*** were common in all the schools I visited. These had as their primary focus the synthesis of creative solutions to known problems; students were given the opportunity to undertake some original research. In many cases these pursuits were sponsored at the governmental level. For example, one school held an annual *Research*

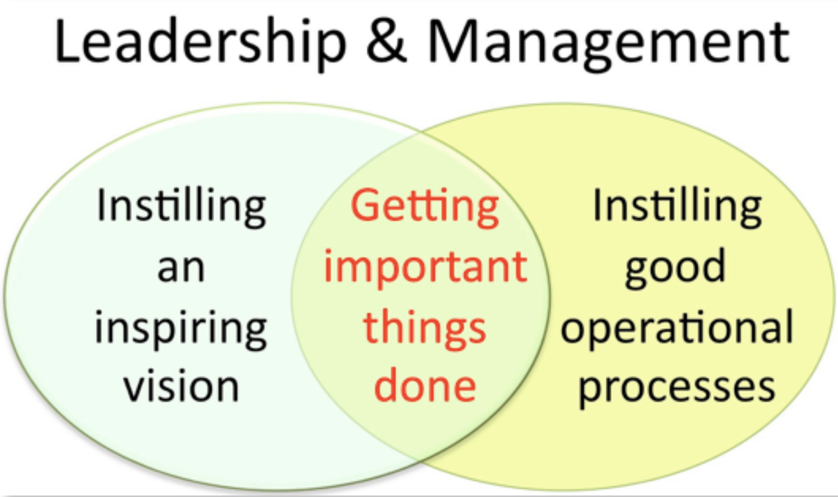
Programme Symposium to recognise the achievements of students, while another had set up an in-house outfit called the *Science Mentorship Research Programme*, which had attracted sponsorship from external agencies such as the Agency of Science, Technology And Research.

- ***National Science Challenges and Olympiads*** were embraced in Singapore to an extent I have never encountered in British schools. A vast number of students were entered into these competitions and in many cases teachers described to me how students were often provided with tutoring and practice to help them excel when faced with the challenging scripts.

3.3.2. The Role of the Senior Leadership Team

A key finding that arose from my visits was the inspirational leadership from the highest levels in Singaporean schools. This appeared to feed energy to to heads of department and teachers throughout the network; all professionals I encountered enjoyed their careers and gained huge satisfaction from them. Needless to say, this culture set in motion learning opportunities for students that were positive and productive in science and elsewhere.

Teachers spoke of leaders who promoted team development opportunities, who listened more than they spoke, who had a a sense of humour and held with them face-to-face, one-to-one meetings often and dealt promptly with issues they raised. They were often seen around the school, including at break times and lunchtimes, and they noticed good practice and displays. They genuinely sought a meaningful expression of views: the opinions of all, whether at meetings or in more general terms, and were happy to take advice themselves. There was not a hint of inequality, negativity or the finger-pointing blame-game culture that can have a corrosive effect in schools and their departments. In essence, many members of the senior teams I met clearly ‘lead by example,’ combining aspects of leadership termed *affiliative* (‘people come first’), *democratic* (seeking consensus on issues) and *visionary* (‘come with me’).



A Venn diagram illustrating how at least one Singaporean Principal saw their role: the best captaincy of a school was built not only asking other 'what and why' (instilling an inspiring vision), but also 'how and when' (instilling good operational processes).

Setting a common goal was a key aspect of practice for the senior leadership teams in the schools I visited. I was fortunate to attend a staff training afternoon at one school, hosted for a number of teachers who were new to the school. In addition to witnessing a policy of the school that the first, standing item on any pre-published meeting agenda is a fixed discussion of one aspect of best practice, I also noted that it was common for Senior Leaders to discuss with their teams things that worked well, and things that didn't work so well in their previous schools - namely, promote ***reflection***, and to orchestrate activities such as mind mapping and holding idea 'hothouses' to direct common thoughtful. For example, one principal, who had the hope of raising students' O-Level outcomes in the upcoming examinations, held a brainstorming session with his team in which he constructed a Venn diagram and showed that improved outcomes, increased student enjoyment and greater effectiveness of teaching and learning intersected to achieve the common goal. In another, teachers were invited to discuss how to motivate the small number of students who feel they cannot achieve: insightful comments such as time pressures, students' susceptibility to peer pressure, and over-estimation of ability were contributions that were particularly noteworthy.

I was fortunate, too, to be able to speak with a member of the senior team in one school who occupied the position of Staff Tutor. She was hence responsible for staff wellbeing and development. Great emphasis is placed in Singapore, I was informed, on developing teachers' skills and capabilities. To this end, ***regular coaching sessions*** are held with staff. I was informed that many in her position use the so-called ***'STRIDE' model*** to structure such sessions, which directs the dialogue to follow six themes:

1. S - Strengths: what is currently going well?
2. T - Target: what do you want to change?
3. R - Reality - what is preventing you from achieving this target?
4. I - Ideas: what possible ways could you move towards this target?
5. D - Decide: what will you do as a result of this conversation?
6. E - Evaluate (later): how did you get on with the action you decided to take?

In essence, the Staff Tutor was keen to ask open questions, rather than instructions. She helped others, through questioning, to identify the gap between where they currently are and where they want to be - and discussed solution that would allow them to get there. In many cases, such coaching sessions overlapped with ***mentoring sessions***, in which *advice* was also provided in addition to constructive dialogue. A positive undercurrent appeared to also apply to lesson observation feedback. This was invariably prompt and focused on positive aspects of the lesson. Areas of development, which were always solution-focused, were much more likely to be taken on board by the recipients as a result.

In Singaporean schools, a wide range of different types of research has been carried out, with research design decided by researchers not the government. Certainly, all of the schools I visited recognised the power of ***research informing practice***. I witnessed at least two Research and Development meetings between school science departments and visiting representatives of the Government's Ministry of Education. In another instance, the school had recently published a book summarising in-lesson research projects that were undertaken in the school (**Photo X**). Articles, which had been written by teachers in a range of schools throughout Singapore, focused on a variety of contemporary teaching and learning strategies, including differentiation, scaffolding, data analysis and curriculum design. It was the view of many teachers with whom I spoke that such a publication elevated the status of teachers and inspired many to pursue a career path in teacher education, or to become so-called 'Master Teachers,' which was described earlier in this report.

One practice that had gained particular momentum in Singaporean schools in recent years, and was promoted wholeheartedly on the part of the Senior Team, was the activity known as ***Lesson Study***. Conceived in Japan in the 1990s, this professional development pursuit involves teachers working in small, heterogeneous groups to discuss a key concept that they wish to develop in their individual lessons, and to plan an actual classroom lesson. After observing how their ideas work in a live lessons with students, they then report on the results - which are also informed by student surveys - so that other teachers can benefit from it. Through my discussions with Senior Leaders, I was informed that this approach takes a more collaborative view to developing and improving teaching and learning in the classroom, as opposed to lesson observations which can sometimes focus too much on an individual's performance. One Senior Leader recognised that, in practice, this technique places great demands on staffing. As such, she had introduced into her school a programmed she termed ***'Lesson Study Lite,'*** which involved colleagues working in pairs to design lessons together.

It was without doubt that the senior leadership teams of the schools I visited supported teachers' undertaking of ***continuing professional development (CPD)***, and in one school in particular I was informed that teachers are provided with timetabled time to gather as a professional learning community, in order to '*further the expertise, intellectual development, professional judgment and networks of teachers in order to improve student learning outcomes*.' Teachers were also able to visit… This contrasts somewhat with the situation in the U.K. In the recent Ofsted Report, the inspectors were highly critical of the limited role that CPD plays in the ongoing career of a typical British teacher. They found that CPD was lacking in many schools, and when it was provided it most commonly took the form of courses run by examination boards, or those focused on enhancing subject knowledge. Although such pursuits are very important in the practice of a teacher, what was missing, it was implied, was high-quality training based on research-informed pedagogy - an area to which Lesson Study and other pursuits belongs. Furthermore, there is, it seems, a paucity in the U.K. of Senior

Leaders who are willing to commit themselves to supporting CPD of any type among their staff, citing staffing and timetabling barriers.

In recognising the need for teachers to keep up with the rapid changes occurring in the world and to be able to constantly improve their practice, Singaporean teachers are entitled to a minimum of a hundred hours' of CPD per year. This may be undertaken in several ways, although most commonly teachers are able to attend courses at the National Institute of Education. To this end, each school also has a fund through which it can support teacher growth, including developing fresh perspectives by going abroad to learn about aspects of education in other countries. In Singapore there is clearly an emphasis on sharing best practice. Teacher networks and professional learning communities encourage peer-to-peer learning and the *Academy of Singapore Teachers* was opened five years ago to further encourage teachers to continuously exchange their ideas and strategies for teaching and learning.

3.3.3. The Role of Heads of Department

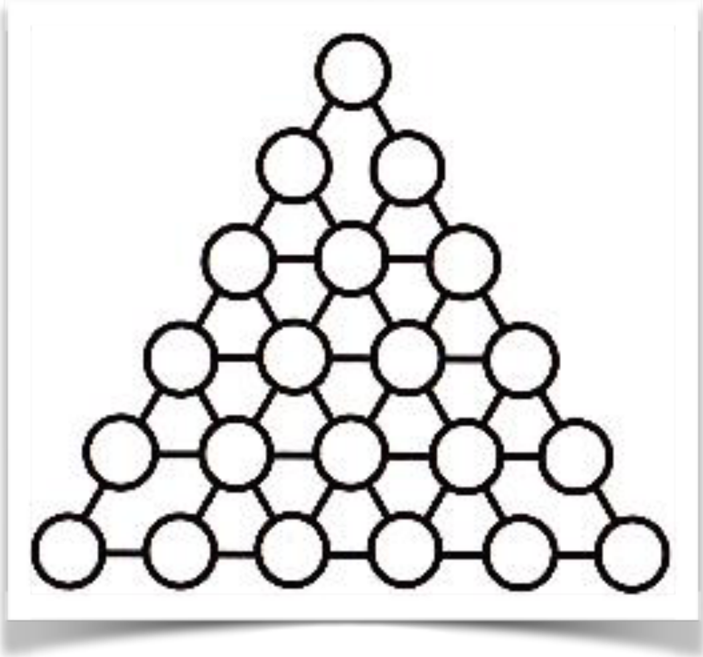
'***Middle Leaders are the engine room of change.***'

National College for School Leadership, 2003.

The organisation of professionals in Singaporean schools closely matches that in their British counterparts. I was somewhat reassured to hear that friction sometimes exists in some Singaporean departments (a common feature of those in which I have worked!), but was inspired by the attitudes of the leaders I met. '*In such a large department there will always be disagreement between individuals,*' said one, '*but the role of the Department Head is to promote quick and effective resolution to maintain a positive and productive atmosphere*.' When questioned how they garnered common opinion and fostered teamwork, soundbites such as '*things are never a 'one-person job' or prescriptive: with the input from all staff I can ensure a common sense of ownership and direction.*'

Ultimately, it is recognised that success in examinations, whether they be of the standard curriculum or international survey type, largely rests on the shoulders of strength of middle management, and that of operational issues. It is the day-to-day activities at the department al level that really drive the progress that students make. In Singapore, all department leaders were able to show me rigorous plans for external examination entries, well-monitored Departmental Improvement plans, surveys of budget and assets register responsibilities, annual evaluation and goal-setting processes and comprehensive Health and Safety policies - all of which echo initiates in the U.K. What struck me as culturally different in many of the schools I visited was their ***Departmental Handbooks***. These described '*the way we do things here*,' and summarised the culture of the department, including its vision, values, procedures, calendar and collegiality, and notably described in detail how everyone plays their part. In one instance, for example, I was informed by a middle leader that her department was well-versed through such a publication in the instructional model of teaching often referred to as the '***E approach***.' In this approach, which can be traced back to a system piloted in the United States in the 1970s, teachers ***elicit and engage*** students by finding out why they know and 'hooking' them into the lesson; ***explore and explain*** the concepts central to the lesson through active, student-centred and self-directed learning approaches coupled with insightful teacher questioning; ***extend and elaborate*** the concepts to push learners into demonstrating and applying their new knowledge; and finally encourage students to ***evaluate*** their learning to ascertain how much progress had been made. She was keen to point out that this, and its predominance in the teaching systems of Singapore, may in part relevantly underpin the country's success in measures of Scientific Literacy. This would certainly cast some light on the predominance of the high-quality teaching and learning activities that I had the pleasure of observing in this school in particular.

One middle leader described how she managed her department using a 'pyramid' approach. This is similar in many respects to ***Maslow's Hierarchy of Needs***, used by psychologists educationalists to illustrate the motivational potential of activities in the classroom. This approach inspired her members to pursue higher levels of practice and is summarised below.



The 6-Step, 21-Component Pyramid of Departmental Management. Produced on the basis of discussions with a Head of Science in Singapore, this framework directed the leader to prioritise aspects of departmental practice that could be seen as ambitious, while avoiding the neglect of the fundamental cornerstones of success.

L1 (Level 1).

To be secure at this level, a Department must ensure that:

1. There is sufficient timetabled time dedicated to the subject in order to teach its syllabus.
2. Students have access to the necessary laboratory equipment and textbooks.
3. There is a purpose-built teaching environment, kept to a high standard of order and cleanliness.
4. There is in place a reliable body of laboratory technical staff who are provided with sufficient notice of practical orders.
5. Students know what they need to know; namely, they are provided with copies of the syllabus, tracking cards, and so on.
6. Teachers are hired who have a command of their subject, and who are provided with information to enable them to deliver specific aspects of the course in a specific timeframe and issue homework and assessment items in accordance with given guidelines; namely,

a scheme of work with prescribed but modifiable lesson plans that have in-built opportunities to allow the teacher to take students on unexpected journeys.

L2 (Level 2).

To be secure at this level, a Department must ensure that:

1. Students are counselled with regard to subject and course choice, their successes are recognised and any imposed sanctions are consistent.
2. Its rooms and spaces are attractive and represent a stimulating learning environment; namely, clear and positively-phrased laboratory rules, the use of exemplar material positioned on a ladder to show different academic qualities, posters of contemporary scientists (e.g. Franklin, Kroto and Nurse) and news stories about topics they are learning, key words (in particular, assessment objectives and command words from the syllabus).
3. Students are provided with revision materials to empower their independent learning; namely, comprise exercise books that contain a set of notes from which students can later reconstruct their lessons, a series of past examination papers that are systematically practised, and trial exams of genuine similarity to those they will sit.
4. Students are afforded with out-of-lesson revision classes and support clinics for students with a given target grade, for example, the use of exemplar materials to tackle longer-answer questions in class.
5. It knows how students are doing in relation to each other; namely, it must have common spreadsheets to collate, analyse and monitor regular and common summative assessment items, perhaps in the form of a 'traffic light' system' in which the teacher could rapidly identify problems and raise them, as well as intervention strategies, including retests, mentoring and parental communication and liaison, for those who underperform or exceed their targets and are identified as gifted.

L3 (Level 3).

To be secure at this level, a Department must ensure that:

1. It sets for its students SMART targets (specific, measurable, achievable, relevant, time-related), perhaps in reflective log in books which are inspected regularly.

2. It encourages amongst its staff an open culture of peer learning and observation to perfect the 'art' of teaching, which includes a non-judgmental peer lesson observation programme and reviews of quality and quantity with regard to homework and assessment.
3. It liaises with students in a virtual environment, in order to remind and/ or receive homework, host forum discussions on enrichment stories, and so on.
4. It provides for students enrichment opportunities to inspire them to learn (for example, trips, competitions, and so on).

L4 (Level 4).

To be secure at this level, a Department must ensure that:

1. It employs, in lessons, sophisticated teaching techniques to further learning. These place dialogic, self-discovery and active learning, rich in personalisation and differentiation, at their centre.
2. It uses data collation spreadsheets that are adjusted to take into account students' developing skills and attitudes, in addition to their academic scores.
3. It provides opportunities for student mentoring, in which older members of the school can liaise with less able, younger, peers, to provide scaffolding in their education.

L5 (Level 5).

To be secure at this level, a Department must ensure that:

1. Students, and members of the Department, are trained to 'think like the examiner' using a range of metacognitive and exam-based task approaches, including the cooperative synthesis of mark schemes.
2. It offers genuine opportunities to garner the thoughts and feelings of its students; namely, it offers 'student voice.' This could be in the form of questionnaires designed as a department about lessons, teaching and learning, with the overarching premise being the improvement of the course for future students.

L6 (Level 6)

***To be secure at this level, a Department must ensure that*:**

1. It is committed to researching practice and incorporated into the system its findings. This is by no means limited to Lesson Study, but is a good starting point.

Certainly, from my own observations and discussions, it was clear that the schools I visited were working at the very highest levels of this pyramid. That said, I sensed very little complacency in the system. Indeed, it is appropriate in this respect to refer to a conversation I had with one Head of Department. He referred to a now famous quote of a British cycling coach, David Brailsford, during the London 2012 Olympic Games. As he put it, success comes from the '*aggregation of marginal gains*:' a tweak here and an adjustment there in the system can all add up to make big changes to students' success. Certainly, I was left with the feeling that a management structure that pays attention to the minutiae of the organisation cannot be underestimated in its positive outcomes on student achievement.

4. Conclusions and Recommendations

I began this report by reflecting on my hope that my findings will have some bearing on future practice, on a local or national basis, in the U.K. To facilitate this, I have summarised the most pertinent points below for benefit of the reader, with reference to the initial aims of the project.

My findings described in **Section 3.1.** would suggest that policymakers in the U.K would do well to consider closer links between government departments, teacher training institutions and schools when sharing and implementing new policies that impact on science education.

My findings described in **Section 3.2.1.** argues that teachers in the U.K. should pay more than lip service to the promotion of dialogic teaching in lessons in order to enhance students' educational gains in the spheres of science and scientific literacy.

My findings described in **Section 3.2.2.** echo the recommendations of a recent Ofsted report in suggesting that teachers should set out to sustain students' natural curiosity first and foremost in issues of science, so that they were eager to learn the subject content as well as develop the necessary investigative skills.

My findings described in **Section 3.2.3.** would indicate that teachers should beware of setting the bat too low for their students in their efforts to promote inclusion in their science lessons.

My findings described in **Section 3.2.4.** lend weight to the idea that British teachers should endeavour to make the activity of revision engaging for students and convey to them means and methods by which they can undertake this independently.

My findings described in **Section 3.2.5.** that teaching was informed by accurate and timely assessment of how well students were developing their understanding of science concepts, and their skills in analysis and interpretation so that teaching could respond to and extend students' learning.

My findings described in **Section 3.2.6.** leads me to believe that teaching should pay closer attention to the way in which they question students and consider this a primary vehicle in building their understanding of science and scientific literacy in real time.

My findings described in **Section 3.2.7.** suggests that teachers are right in their belief in the educational value of practical work in class, but ought to provide opportunities for students to take greater control of the design, undertaking and evaluation of hands-on tasks.

My findings described in **Section 3.2.8.** suggests that it would be fruitful in British classrooms for students to receive greater guidance with regards to 'how to learn,' not least in gaining a greater understanding of the examination process.

My findings described in **Section 3.3.1.** suggests that British schoolchildren might be offered further extra-curricular opportunities, particularly with a focus on research and innovation, in order to enhance their cognitive gains in science and boost their scientific literacy.

My findings described in **Section 3.3.2.** suggests that there is much to be said for inspirational senior leadership in securing marked success in students in science, and other subjects, and British schools ought to recognise this more widely.

My findings described in **Section 3.3.3.** suggests that the role of middle managers in driving the day-to-day work ethic and academic progress of students in science cannot be underestimated and that those who hold these positions in British schools ought to be afforded more time and additional help to uphold this role.

In addition to these specific recommendations, I came to the opinion that we have three more general lessons to learn from Singapore with regard to Science education. These are described below.

First, it is important that we, like Singapore, come to avoid syllabus and curriculum writers 'taking sides' in the so-called 'skills-knowledge debate.' I often sense in the British science education system that those responsible for setting schooling have a preference for students learning either key knowledge, or key skills. A notable swing towards more knowledge-based courses was, in recent years, preceded by the change in British government in 2010. In Singapore, the examined curriculum - a list of core content in the right developmental sequence comprising the things that are prescribed and largely factual in nature - is combined masterfully with the school curriculum, which is rich, expansive and contextual, and provides a wide range of personal and social opportunities which cannot readily be stated in detail by the exam boards. That many critics claim that Singapore is focusing on creativity and innovation, as an argument against watering down the content of British syllabi, lapses into the false opposition between knowledge and skills, and fails genuinely to understand the policy and practice in Singapore. Rather than ‘instead of’, the Singaporean policy is ‘as well as’.

Second, it is common in the U.K. and in many countries for some students to disregard their abilities in science during their secondary school years. I have lost count of the number of times I have encountered a student who has given up on the subject, seeing themselves as ‘rubbish at science.’ Furthermore, technical education is often looked down upon in Western societies a dead-end option, of low quality and typically out of step with the changing needs of employers. Based on my observations in schools in Singapore, I feel we would do well to ***limit the extent to which we ‘label’ students*** and also take on board its ***positive approach has to scientific vocational education***. This has been an important pathway in Singapore’s journey to educational excellence and real value is attached to it. Much of this sentiment was achieved through the efforts of the Institute for Technical Education (ITE), founded in 1992, which transformed the content, quality and image of vocational education to combat the societal prejudice against less academically-inclined students. It promoted and rebranded its kind of ‘hands-on, minds-on, hearts-on’ applied learning and enrolment has increased ever since as children see it as a path to a bright future. Part of the reason for the success of the technical education at ITE is that students get a strong academic foundation early in their academic careers so they can acquire the more sophisticated skills required by leading edge employers. Perhaps, then, the fact that there are opportunities in science presented for all, and no student is left feeling that science is ‘not for them,’ could be another reason for the motivation and hence success of Singaporean students for the subject. This may in part underpin their success in international measures of scientific literacy.

Third, and finally, I feel that it would pay dividends in later schooling to provide British pupils with more coverage of science in their primary years. The Ofsted report, to which I gave referred throughout my findings, largely agrees, and in Singapore we have an example of the benefits that can be brought by building foundations in the subject at an earlier age.

It is on this complex backdrop of international comparisons in education and a rapidly-changing technological world that we go forward into the 21st Century. As citizens we are all hopeful that science will deliver further benefits to our lives, but are wary of the dangers it also might bring. We must keep any new findings firmly anchored to cultural and economic considerations. Indeed, as Sir Winston, our first nuclear Prime Minister, claimed, '*science, must be the servant and not the master of man.*'

5. Acknowledgments

I would like to thank the very helpful staff at the **Winston Churchill Memorial Trust** and the **Mercers' Company** for very kindly funding my Fellowship and for their continued support and interest in the project.

I would also like to thank in particular the following people for hosting and supporting me during my time in Singapore, and more generally the wider body of staff and pupils at each of their schools.

- Anglican High School - **Ms Janet Wee** (Head of Partnerships), **Mr Vincent Kang** (Vice Principal: Academic) and **Mr Joseph Tam** (Head of Science).
- Balestier Hill Secondary School - **Mr Abdul Harris Bin Sumardi** (Principal) and **Mr Justin Lee** (Head of Science).
- Bedok View Secondary School - **Mr Jeffrey Low** (Principal) and **Mr Abdul Malik Osman** (Head of Science).
- Dunman High School - **Dr Suan Fong Foo** (Principal), **Mr Chin Teck Lee** (Vice Principal: Academic) and **Ms Serene Lam** (Head of Partnerships).

Finally, I would like to thank **Dr Elaine Wilson**, Senior Lecturer at the Faculty of Education at the University of Cambridge, and **Mr Michael Skelly**, Headmaster of Westcliff High School for Boys, for their assistance throughout my application for the Fellowship.

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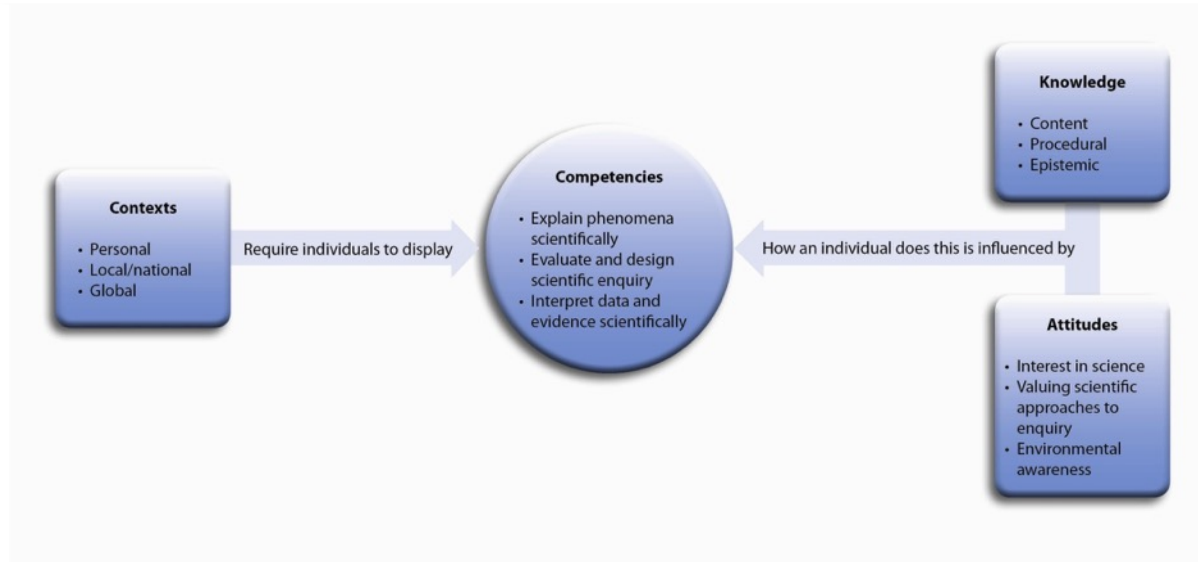
7. Appendices

Appendix 1: Singapore Country Profile

Language(s)	English (official language); Malay (national); Mandarin Chinese; Tamil[5]
Population	4 987 6006
Growth rate	5.3%[7] (OECD 0.68%; World 1.19%)[8]
Foreign-born population	Chinese: 74%; Malay: 13.4%; Indian: 9.2%; Other: 3.2%[9]
GDP per capita	USD 37 293[10]
Economy-Origin of GDP	Electronics, petroleum refining, chemicals, mechanical engineering and biomedical sciences sectors[11] Manufacturing: 26% (2005)[12]
Unemployment	3.2% (2008)[13] (OECD average 6.1%)[14]
Youth unemployment	Females (15-24 year-olds): 11.1%; Males (15-24 year-olds): 6.9% (2007)[15] (OECD average 13.8%)[16]
Expenditure on education	2.8% of GDP[17]; (OECD average 5.2%)[18] 15.3% of total public expenditure[19], (OECD average 13.3%)[20] of which: 21% on primary education 33% on secondary education 34% on tertiary education 12% on unknown[21]
Enrolment ratio, early childhood education	No data (regional average 49%)[22]
Enrolment ratio, primary education	106.2% (2007)[23] (regional average 110%)[24]
Enrolment ratio, secondary education	76.4% (2007)[25] (regional average 77%)[26]
Enrolment ratio, tertiary[27] education	No data (regional average missing)[28]

Appendix 2: The OECD Framework for Scientific Literacy



Appendix 3: Background to the Visited Schools

Anglican High School

This school is one of the oldest in Singapore, having opened in 1956. It has grown substantially and now has over 1,500 students on roll. It was made a bilingual Special Assistance Plan school in 1979 and in 1995 the government awarded it Autonomous status, giving the school greater control over its affairs. It offers the Integrated Programme for gifted students. The school is currently led by school principal Mdm Maureen Lee. Further information can be obtained from its website, www.anglicanhigh.moe.edu.sg

Balestier Hill Secondary School

This school was opened in 1964 and has 1,150 students on roll. It is a mainstream school and also accepts a special group of HI (hearing-impaired) students. Since 1991, the school has had Pastoral Care and Career Guidance (PCCG) and Cognitive Research Trust (CoRT) programmes. Its current principal is Mr Abdul Harris Bin Sumardi. Further information can be found on the school's website, at http://www.balestierhillsec.moe.edu.sg

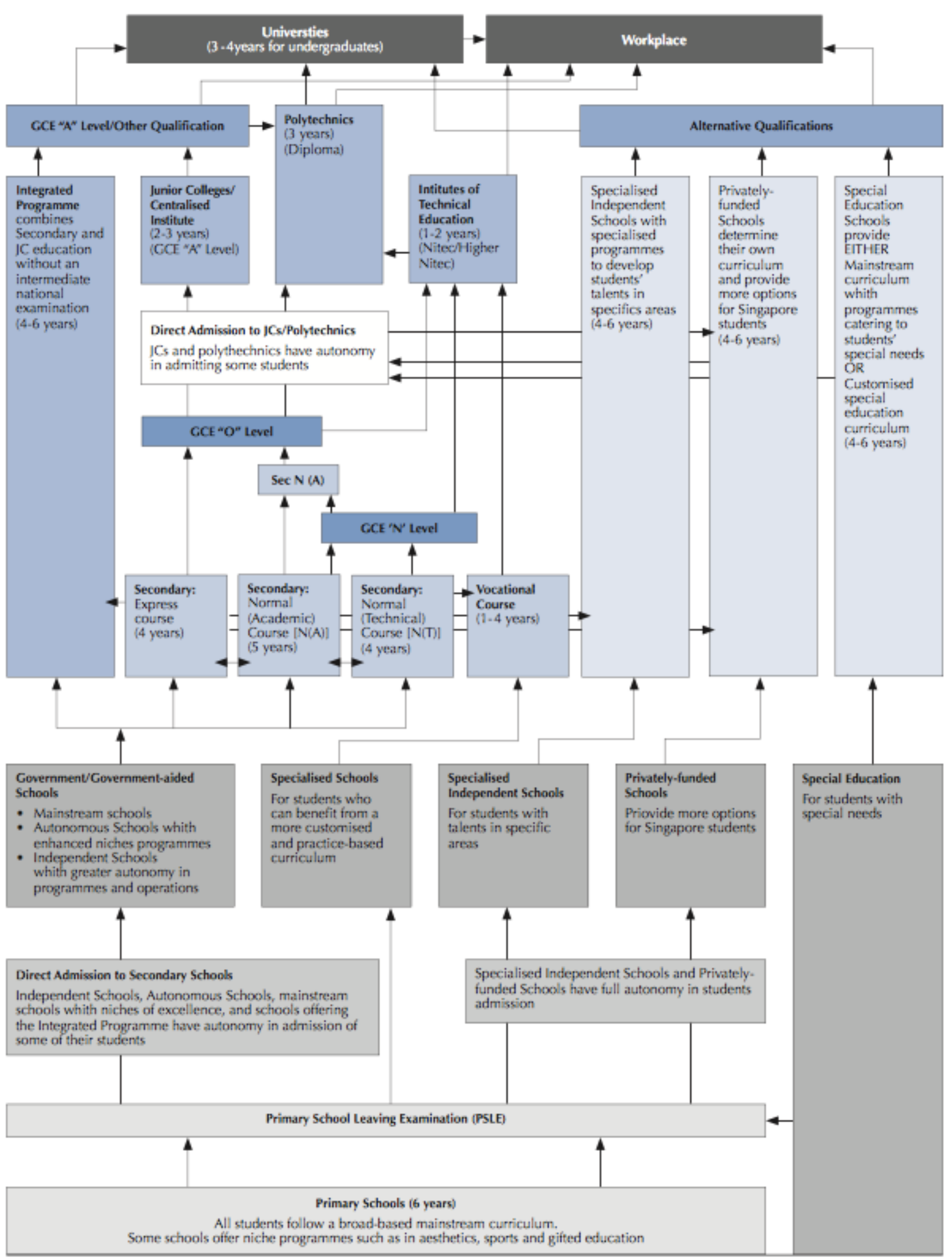
Bedok View Secondary School

Founded in 1977, this school consists of 36 classrooms, a language laboratory, a commerce room, two computer laboratories and six science laboratories; in addition, a sports hall has been completed, which is available for the use of the public. The school enrolment comprises 240 students in each level, with 4 classes of the Express stream, 2 classes of the Normal Academic stream, and 1 class of the Normal Technical stream. Mr Jeffrey Low is the Principal and further information regarding the schools is provided at http://www.bedokviewsec.moe.edu.sg

Dunman High School

Like Anglican High, Dunman High School was established prior to Singaporean independence and is an autonomous institution that offers the Integrated Programme for gifted students. It is one of the largest government schools in Singapore in physical area and also one of the top performing in terms of examination outcomes. The current Principal is Dr Foo Suan Fong and its website is http://www.dunmanhigh.moe.edu.sg

Appendix 4: A Summary of the Education System in Singapore



Appendix 5: Photographs

Photo 1: Students undertaking group practical work focused on data logging of pH values.

Photo 2: Students taking the place of the teacher and hosting a session on experimental technique.

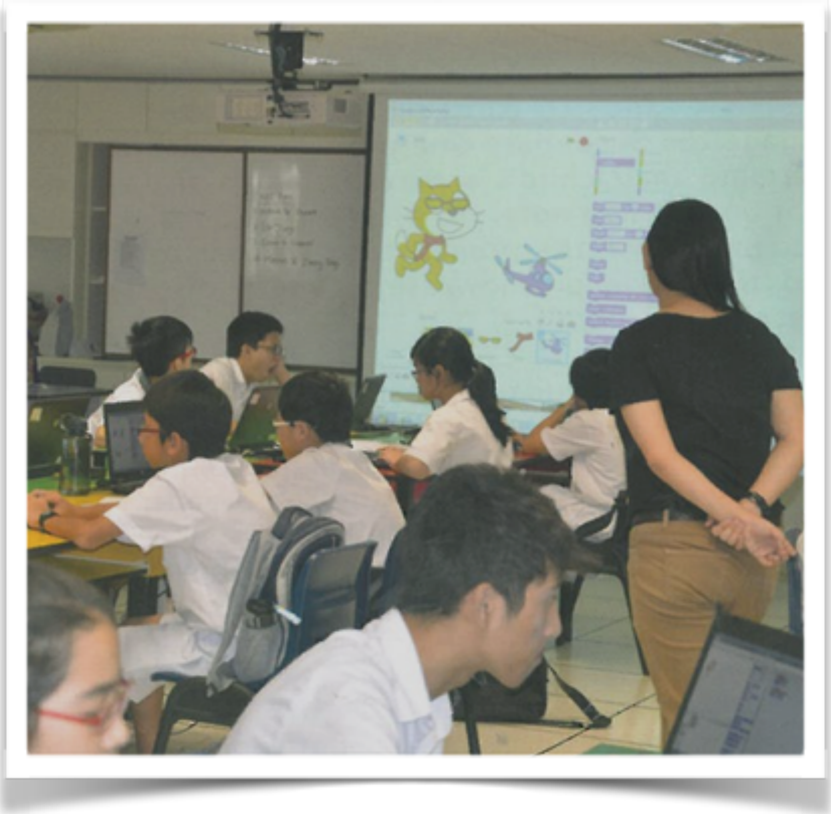


Photo 3: The use of laptops, and other technical devices, was commonplace in the schools.

Photo 4: Practical work noticeably increased the depth and breadth of dialogue between students.

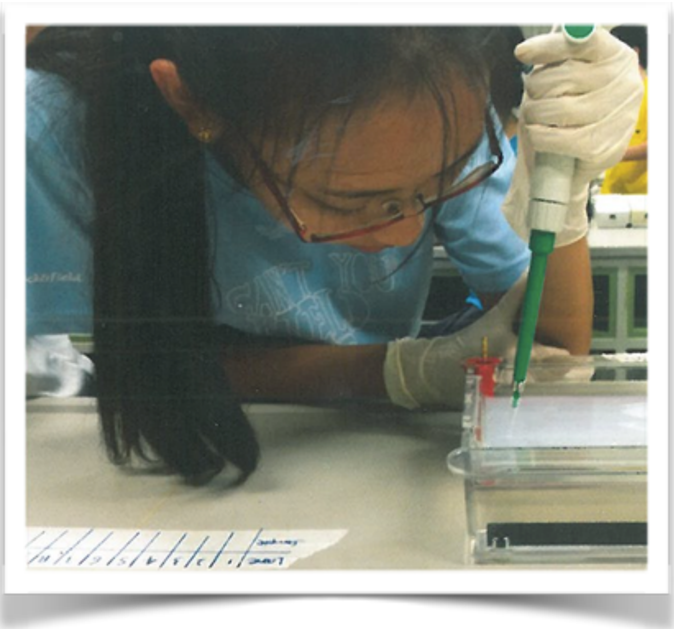


Photo 5: Pupils were also commonly seen to undertake practical work on an individual basis.

Photo 6: Engaging in ‘vertical farming’ as part of their extra-curricular pursuits.

Photo 7: Robotics clubs were remarkably common in Singaporean schools and were very popular.

Photo 8: Students engaged in research projects, as part of their extra-curricular pursuits, were sometimes able to present their work to distinguished panels.

Appendix 6: Dissemination

Since my return to the U.K. I have:

1. Given a presentation to members of the Science Department at Westcliff High School for Boys in Essex.

2. Communicated my findings to members of the Faculty of Education at Cambridge University, and Senior Leaders in schools throughout the East of England affiliated with the Faculty of Education.

It is now my intention to send my report to:

1. All Heads of Science and Head Teachers in the Essex local authority.

2. All Examination Boards that administer examinations in England and Wales.

3. The Royal Society, Science Community Representing Education and The Association of Science Education.

4. Government Ministers with responsibility for science education in schools.