
APPENDIX 3:
REPORTS FROM THE
OVERSEAS VISITS



GATSBY

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I. INTRODUCTION

This appendix contains the full reports from each of the six country visits.

We carried out a preliminary survey of 11 countries, described in Appendix 2. From it, we selected six countries¹ for the overseas visits. We selected countries that we knew from international comparisons such as PISA and TIMSS to be successful in science education, and where our preliminary survey had identified an expert witness who would be well placed to help us organise and inform our visits. These expert witnesses were both knowledgeable about science education in their country, and independent enough to give an objective view. Typically, they were university academics specialising in science education: their names are in the individual country reports.

The six countries we selected to visit are listed below. Detailed reports from each visit follow in this appendix.

Australia (Victoria), chosen for its success in science education and its cultural similarity to the UK. We visited four secondary schools in the greater Melbourne area (one being independent, the others state-funded) and two science centres.

Finland, chosen because of its consistently successful science education and the similarity of its comprehensive system to the comprehensive norm in the UK. We visited three schools in the Helsinki region and met teachers and officials at the Finnish National Board of Education.

Germany, chosen for its success in science education. We visited three academic secondary schools (gymnasia) in the Hamburg and Kiel region and met teachers and science education researchers.

The Netherlands, chosen for its successful science education and its cultural similarity to the UK. We visited three general academic schools (VWO and HAVOⁱⁱ) in Amsterdam and Utrecht and had a workshop with teacher trainers in Amsterdam.

Singapore, chosen for its consistently successful science education and its historic links with the UK education system. We visited three secondary schools across Singapore and met with officials and master teachers at the Academy of Singapore Teachers and with science education academics at the National Institute of Education.

The USA (Massachusetts). Massachusetts is the highest-performing US state in PISA. We visited three high schools in the Boston area and met officials in the Massachusetts Department of Education and the Boston Public School District.

Altogether, we visited a total of 19 schools across six countries. At each school we observed lessons, toured the science facilities and talked with students, science teachers, science department leaders and school leaders.

ⁱ In some cases, we selected specific states within a country, such as Massachusetts in the USA, and Victoria in Australia, on the basis of the known international performance of those states.

ⁱⁱ In the Netherlands, VWO schools are pre-University, and HAVO schools are general academic.

APPENDIX 3:
COUNTRY REPORT:
AUSTRALIA (VICTORIA)



GATSBY

I EVIDENCE GATHERING

This report has been written by John Holman and Beth Jones and is based on the following sources. Further details of the sources are in Annex 1.

- A. Desk research.
- B. Visits to schools in Melbourne: Roxburgh College (public school, years 7–12) on 7 March 2016; Penleigh and Essendon Grammar School (PEGS, independent school, K to year 12) on 8 March; Blackburn School (public school, years 7–12) on 8 March; and Melbourne Girls' College (public school, years 7–12).
- C. Visits to two science centres: Quantum Victoria on 7 March and Gene Technology Access Centre (GTAC) 7 March 2016.
- D. A meeting with Professors Russell Tytler of Deakin University and Vaughan Prain of La Trobe University on 9 March 2016.
- E. A visit to Museum Victoria on 8 March 2016.

The visits and meetings in Melbourne were organised by Dr Graeme Oliver of La Trobe University, Melbourne. He also provided individual expert advice throughout the visit.

2 OUTLINE OF EDUCATION IN VICTORIA, AUSTRALIA

This is a summary; there is further detail in Annex 2.

Australia is a federal country with eight states or territories, of which Victoria is the second largest, with a population of 5.55 million out of a total of 23.5 million.¹ Like most of Australia, the population is concentrated in coastal cities: in the case of Victoria, by far the largest is Melbourne, population 4.09 million. Outside the cities the population density is very low.

States are largely autonomous in education policy, and until 2010 there was no federal national curriculum. Victoria has its own independent policies for curriculum, assessment, teacher employment and school organisation. There is a relatively high proportion of independent, fee-paying schools in the state, attended by 25% of students. Independent schools have a small federal contribution to running costs: at PEGS this is 26%, but it varies according to need in the area.

The school year usually starts in late January or early February and runs until mid-December, with a short holiday between terms and a long summer holiday in December and January.

Victorian education is successful by Australian standards – it is the highest achieving state after the Capital Territory (which is very small). Australia as a whole does well in international educational comparisons: it was ranked 10th (out of 37) in the 2012 PISA science tests.

The state-funded secondary education system is broadly comprehensive. There is a high degree of parental choice: around 96% of Australian students attend a school that competes for enrolments with at least one other school. Most secondary schools are year 7 (age 12) to year 12 (age 18). Compulsory schooling lasts until age 17 but over 84% of Australian students stay on to year 12. Both general and vocational programmes are offered in upper secondary schools. Students completing an academic pathway are awarded a Victorian Certificate of Education (VCE), and those on a vocational pathway during years 11 and 12 are awarded the Victoria Certificate of Applied Learning (VCAL). Scores in the VCE are used to compile the Australian Tertiary Admission Rank (ATAR), which is used to decide which universities the student can get into. The ATAR algorithm includes a weighting for perceived subject difficulty.

Of the 55,500 students that completed year 12 in Victoria in 2015, 53.2% of them enrolled onto a bachelor's degree. Students normally attend a university near their city, leading to a close relationship between schools and a small number of local universities. Australian universities are highly rated by international standards. As in England, Vocational Education and Training (VET) has a lesser reputation, and there are multiple initiatives to improve VET to meet the demands of the labour market.

¹ www.data.oecd.org/australia.htm

2.1 ACCOUNTABILITY

Victorian schools operate under an accountability regime that is much lighter-touch than England's. School performance data is available from the Myschool web portal, a comprehensive and easily used system giving comparative data (on test results, attendance, finances etc) for all schools in Australia.

There is no inspectorate. School principals are held to account by senior instructional leaders from the Victorian Regulation and Qualifications Authority (VRQA), who draw on the results of the school's self-audit. There are standardised parents' and students' surveys which schools are required to carry out each year, the results of which are published. In some schools, students are also asked to reflect on the pedagogy of teachers.

3 SCIENCE EDUCATION IN VICTORIA

3.1 SCIENCE IN THE SCHOOL CURRICULUM

Curriculum

The basic requirements are laid down by AusVELS (Australian Curriculum through the Victorian Essential Learning Standards): this is Victoria's interpretation of the Australian national curriculum, which applies up to year 10. However, curriculum documents allow wide scope for interpretation, and schools in Victoria have much autonomy in the way they interpret them. So there is wide variability among the curricula followed by different schools.

In secondary school, students generally take a common course in science in years 7, 8 and 9, taught as general science. In year 10, there are elective options usually based on the declared science subjects of biology, chemistry, environmental science and physics. In Penleigh and Essendon Grammar School, the newly-introduced year 10 science scheme consists of a series of five integrated thematic modules, of which students must choose a minimum of two. In other schools, the organisation of year 10 science is more traditional.

In years 11 and 12, students choose among the subject units offered by the Victorian Certificate of Education (VCE), which includes 90 study or subject units, 30 of which are vocational. Schools decide which options they will offer. To graduate the VCE, students must satisfactorily complete a minimum of 16 units: of these, 13 can be from VET. Most students graduate with more than the minimum number of units. Teaching in years 11 and 12 follows the VCE syllabus quite closely.

About 60% of students take at least one science subject at VCE. The most popular science subjects are psychology (sic) – taken by 35% of girls and 15% of boys, biology – taken by 30% of girls and 15% of boys, chemistry – taken by 20% of girls and 20% of boys, physics – taken by 20% of boys and 10% of girls. It is not possible to provide figures on students doing multiple science subjects and the combinations of subjects they are taking. However, there are concerns about low rates of progression to science in VCE: Australia has one of the lowest rates in the OECD of progression to post-compulsory science.² Like many other countries, we heard that uptake into physical sciences and maths was significantly gendered.

The Victoria Certificate of Applied Learning (VCAL) is a vocational alternative to VCE in years 11 and 12. It includes practical work-related experience, as well as literacy and numeracy skills. In Roxburgh College, for example, about half of students follow the VCAL route, but in Melbourne Girls' College no students do.

Assessment

Below year 11, the only external assessments are in numeracy and literacy (maths and English). Students take the National Assessment Program Literacy and Numeracy (NAPLAN) assessments in years 3, 5, 7 and 9.

Beyond these, all school assessments in years 7 to 10 (including those in science) are set and marked by teachers, including regular portfolio assessment tasks and end of year school exams.

The VCE is largely externally assessed and, because of its critical role in determining university entrance, it plays a powerful part in shaping what goes on in years 11 and 12. 60% of a science VCE Stage 2 grade is based on a written exam, 40% is internally assessed. The nature of the internally assessed component varies between science subjects: in physics, for example, it comprises a combination of school-based tests, an essay and an

² www.audit.vic.gov.au/publications/20120606-Science-and-Maths/20120606-Science-and-Maths.pdf and www.eprints.qut.edu.au/73153/1/Continuing_decline_of_science_proof.pdf

extended practical investigation of 8–16 hours. The assessment system is currently in a process of reform, with the new VCE ‘study designs’ (specifications) being introduced in January 2016. During our visit, students in year 11 were studying the new qualifications and year 12 were the final year to be studying the old system. The weighting of internally and externally assessed components remains the same, but the sciences now all have a larger investigative component. Part of their second year of study will involve undertaking an investigation and presenting it in a poster format. Students will also be required to keep a log book of all their practical work, which can be used as an assessment tool by teachers if they choose to. Assessment of the first year of study (units 1+ 2) relies solely on a school’s judgement and does not get reported to the VCAA. It is the second year (units 3+4) that determines the students’ final score. Teachers are given advice within the VCE study design about ways in which they can assess students through the course. They are free to choose their approach but must vary it throughout the course. Assessment approaches include annotated log books, media analysis and reports on investigations.

The introduction of an extended investigation across all three sciences, and its more prominent position in the VCE, was in response to pressure from universities for a greater proportion of extended investigations.

Schools have considerable autonomy in deciding how to carry out these internal assessments for the VCE, provided they are within the required criteria. At Stage 2 teachers’ internal assessment marks are moderated statistically against the mark in the examination.

Science teachers

Secondary teachers are licensed to teach a particular subject specialism at VCE level and are not supposed to teach outside it. Principals, however, have considerable discretion in making teaching appointments, and there is no formal monitoring of the adherence to the specialism requirement. The licence to teach is issued by the state in which the teacher works (in this case, The Victorian Institute of Teaching). Most secondary teachers have a degree-level qualification together with a Masters level postgraduate teaching certificate, which nominally takes two years of study but can be achieved in a single year by treating teaching practice as part of the first year of teaching. (No longer so.) A teacher’s practical skills are not focused on within their training route; they are expected to develop them ‘on the job’.

According to the OECD, teachers in Australia have a higher than average proportion of contact time, and consequently less time available for lesson preparation and professional development. We were told that there are few incentives to take part in continuing professional development (CPD), though there is an expectation, audited by the Victorian Institute of Teaching, that teachers do 100 hours of CPD over a 5-year period in order to remain registered. Most of the CPD we heard about was generic rather than subject specific, though the Science Teachers’ Association of Victoria (STAV) runs a programme of science-specific CPD. STAV also has a technician arm; LabTech. We were told that there is not a lot of CPD specifically related to practical science: ‘We mainly rely on our colleagues’.

Schools also support their teachers to learn from one another. In several schools we visited, schools had initiated learning communities, in which key areas were focused upon within small teams of teachers from different disciplines.

3.3 SCIENCE BEYOND THE CURRICULUM

The network of science centres was established in Victoria in 2012, following an initiative by Victorian Government to provide opportunities for students to experience cutting edge scientific research and developments. We visited two centres in Melbourne: Quantum Victoria, specialising in the physical sciences, and the Gene Technology Access Centre (GTAC). There are six centres spread across Victoria, each specialising in a different aspect of science or technology. The centres have performance criteria requiring them to engage with all schools in Victoria, with particular emphasis on inaccessible rural schools and on socioeconomic deprivation. They have an interesting model for reaching remote rural schools, involving a combination of ICT, video links and outreach visits. There is an interesting model for managing practical work through video link. GTAC run a particularly interesting programme, which trains and pays PhD students to run practical sessions with students. Sessions are supervised by a member of staff who is trained as a teacher, and paid in line with school teachers.

The science centres are very well equipped with laboratories and equipment, and there is a strong emphasis on practical activity. At GTAC, we were told there is a lot of interest in using the centre's facilities for VCE assessed investigations. The centres also provide CPD for the teachers accompanying their classes.

Museums Victoria is a federation of interlocking museums including the Melbourne Museum and Science Works, both of which have extensive science collections. The museums have 17 million specimens, three-quarters of which are science-related. They are seen to be an integral part of the Victorian education system. The Museums use the science centres for outreach as well as having extensive on-site programmes. 59% of schools in Victoria come to the museums: there are nearly 300,000 student visits a year. Many of the on-site activities involve practical science.

One of their most successful exhibitions to engage teenage students is their 'Top Design' event.³ This exhibition displays the best project work produced by VCE design students as part of the VCE 'Season of Excellence'. Final products are displayed alongside portfolios of work and a season of talks runs alongside the show. They are currently exploring whether it would be possible to use a similar model to showcase excellence within the new VCE science investigations.

There are opportunities for schools to visit university laboratories to see and use modern equipment such as spectrometers. Given that most Victorian schools are in the greater Melbourne area, such opportunities are within reach of the majority of schools, but teachers felt they did not make the most of them.

4 RELEVANT FINDINGS

The schools we visited were well-ordered and purposeful, with enthusiastic, motivated teachers. Students were co-operative and well behaved. Teachers appear to be genuinely motivated by the value of teaching rather than in response to any accountability system.

4.1 TYPES OF PRACTICAL SCIENCE

The types of practical science we saw were similar to England: a mixture of short experiments designed to confirm theory, and longer more investigatory experiments. In years 11 and 12, a significant amount of time is spent on practical assessments.

Science teaching and practical work are approached with appreciation for the range of cultures and experiences of the students. In PEGS we saw a lesson in which Aboriginal Dreamtime stories were used to introduce astronomy.

4.2 HOW FREQUENTLY?

As always, it is difficult to gauge how frequently practical work is done. The average seems to be about once a week at all levels – similar to, but perhaps a little less frequent than, England. Lessons were often approximately 70 minutes in length.

4.3 ATTITUDES TO PRACTICAL SCIENCE

Practical science is unquestioned as a core part of science teaching. Teachers told us that practical work:

- is motivating and enjoyed by students
- consolidates learning
- gives students skills that will be valuable later, for example at university
- helps give a sense of being a 'real scientist'.

³ www.museumvictoria.com.au/melbournemuseum/discoverycentre/top-designs

Teachers felt that authentic hands-on experiences are essential to stimulate curiosity. Unexpected outcomes are an important part of that authenticity. The cognitive dissonance between what is expected and what actually happens helps to strengthen conceptual change. The importance of the unexpected was reinforced by several of the students we spoke to: one told us how they had distilled cola to get pure water: “But the interesting thing was the gunk that was left behind”. Another told us about mixing lead nitrate and potassium iodide solutions: “I knew it would turn yellow, but I didn’t expect the weird streaks”.

In the strongly multilingual Roxburgh College, we were told that for students with poor English, practical work is a valuable way to reinforce learning through concrete experiences. Teachers felt that their own practical skills enabled them to model correct techniques and enhanced their professional status. Their autonomy also allowed them to explore different approaches to practical work: one teacher explained how they made use of the school’s teaching kitchens during chemistry lessons.

The influence of assessment pressure is not felt until the end of the VCE. We heard that some students may ask: “Why are we doing this experiment when we could be practising exam questions?”, but that this is mainly confined to year 12 if it happens at all.

Teachers emphasised the importance of discussing practical work results, preferably in the same lesson in which the experiment is carried out.

4.4 FACILITIES AND FUNDING

The laboratories we saw were mostly well designed, with flexible facilities that allow both theory and practical work. Typically, labs have fixed benches projecting outwards from the wall, provided with services, and moveable furniture in the middle. Similarly to England, class sizes are up to 25, and students work in groups of two or three. The number of labs for a given size of school was similar to England. Most of the labs were modern and well maintained. In the independent PEGS, we were told that high quality labs are an important way to attract parents.

Typically, we were told that funding for equipment was adequate and that funding never presented a barrier to practical science. In schools such as Roxburgh and Blackburn, with rapidly growing numbers of students, laboratories can be stretched. Funding is based on predicted numbers of students over a 5-year period, so rapidly changing communities can sometimes be underserved. The process of buying equipment was also similar to the UK: technicians would often be tasked with looking through catalogues of equipment to find the best deals. We were told that it was deemed too bureaucratic to set up a centralised system.

Text books were used regularly by teachers, with students often having their own set of science text books. PEGS had moved towards e-text books, which allowed content to be updated and for teachers to pick and choose where they wanted to direct students.

At Roxburgh and Melbourne Girls College, we heard plans to create STE(A)M spaces within the schools that would allow more open ended, student led projects. This would be a space to explore 3D printing, coding or invention.

Schools’ provision for ICT seems similar to schools in England, and most students have their own iPads or portable computers. However, although we saw one excellent lesson involving gas sensors, we did not see or hear about extensive use of ICT in lessons. We were told: “We do not use it as much as we should”. Limiting factors appear to be time, availability of working equipment (especially data loggers) and teachers’ know-how.

4.5 TECHNICAL SUPPORT

All the schools we visited employed technicians to support practical science, with well-stocked prep rooms. However, the number of technicians in a given size of school was significantly lower than in England. In Roxburgh (1347 students) there were 1.3 full-time-equivalent (fte) technicians, supporting an estimated 10–15 practical classes per day; in Blackburn School (1100 students) there were 1.4 fte; at Melbourne Girls’ College (1300 students) 1.0 fte; at the independently funded PEGS (2400 students) there were 3 fte. We did however hear that there was a relatively high turnover of technicians, as many were skilled graduates but the salary would never rise above that of a beginner teacher.

In the schools we visited, a significantly smaller number of technicians appeared to be supporting a similar, or only slightly lower, level of practical activity to England's. What might be the explanation for this? It could be that Australian technicians are more productive: those we met were certainly well qualified and highly motivated. Another explanation could be that teachers do a more limited range of practical work, enabling technicians to work more efficiently. We also heard from teachers in Roxburgh that they share out the preparation of practicals to save time. Several teachers will carry out the same practical in a week, and one teacher will take the responsibility for ordering and checking the equipment. One technician told us: "To get everything done, you need to have your teachers in line".

4.6 PROJECT WORK

We saw few examples of extended science projects. Assessment for the VCE allows scope for students to carry out investigations, but we got the impression that these are often formulaic and designed to optimise performance in assessment. Nevertheless, the science centres offer rich opportunities for investigative practical work.

4.7 ASSESSMENT OF PRACTICAL SCIENCE

See section 3.1.

In general, assessment does not bear down as heavily on Australian schools as in England, partly because of the lighter accountability framework. This is partly because there is no high-stakes assessment at 16: the only high-stakes assessment is the VCE at the end of secondary schooling. Consequently, for most secondary school classes, teachers are free to use practical work to support learning in whatever way they see fit.

5 EMERGING LESSONS FOR ENGLAND

1. In many ways, Australia in general and Victoria in particular is a useful comparator for England, being culturally and economically similar, with a secondary school system that is broadly comprehensive and a significant independent sector.
2. One aspect of Australian education that is strikingly different is the much lighter touch accountability system, with no inspectorate and less emphasis on exam results in school accountability. Despite this, Australia out-performs England in international comparisons. The significance of parent and student feedback is also striking.
3. The only high-stakes assessment in Victorian secondary schools is the VCE at the end of secondary schooling. There is no assessment before this, beyond the testing of literacy and numeracy in years 3, 5, 7 and 9. This means that the distorting effects of GCSE assessments at age 16 are absent and science teachers have a relatively free run until at least the beginning of VCE in year 11. In England, there could be a case for downgrading GCSE to assessments in maths and English only, thus freeing most subjects from the burden of assessment, which in science bears particularly on practical work. With the end of compulsory education moving to age 18, this could be a logical step for England. However, care needs to be taken: such a move might downgrade the priority given to science (as was the case when assessment of science was removed in primary schools).
4. We have had confirmation of our existing ideas about the purposes and value of practical work, and some new insights. In particular: "Teachers felt that authentic hands-on experiences are essential to stimulate curiosity. Unexpected outcomes are an important part of that authenticity. The cognitive dissonance between what is expected and what actually happens helps to strengthen conceptual change. The importance of the unexpected was reinforced by several of the students we spoke to".

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5. The rich menu of out-of-school practical science within reach of most schools in Victoria – science centres, museums and universities – and the apparent readiness to use these opportunities, enriches practical science. The science centre model may be worth examining, including:
 - A. their use of PhD students to teach visiting school students; and
 - B. their outreach work with rural schools.
 6. The VCE 'Season of Excellence' showcases the best work of students at VCE in public exhibition spaces. This not only creates a purpose for students to do well beyond an exam result and ATAR score, but also provides students with the opportunity to see 'what good looks like'. The Melbourne Museum is considering a similar approach to the new science investigation unit in VCEs. This could be a way of showcasing top science students in the UK, for example in the CREST or Extended Project programmes.
 7. A large proportion of assessment within VCEs is trusted to the teacher. Guidance on appropriate approaches is provided in the 'study design' documents but teachers are given freedom to choose the most appropriate approach for their students. The suggested approaches to assessment are also varied and include video, annotated log books, media responses, presentations and practical investigation reports.

ANNEX I: SOURCES OF EVIDENCE

A. DESK RESEARCH.

Main sources (accessed March 2016)

OECD Data website, Australian statistics, www.data.oecd.org/australia.htm

Science and mathematics participation rates and initiatives, Victoria Auditor-General's report, June 2012 www.audit.vic.gov.au/publications/20120606-Science-and-Maths/20120606-Science-and-Maths.pdf

The continuing decline of science and mathematics enrolments in Australian high schools, Kennedy, J., Lyons, T., Quinn, F. Teaching Science. Volume 60, Number 2, June 2014. www.eprints.qut.edu.au/73153/1/Continuing_decline_of_science_proof.pdf

Education policy Australia, OECD, June 2013 www.oecd.org/education/EDUCATION%20POLICY%20OUTLOOK%20AUSTRALIA_EN.pdf

www.ausvels.vcaa.vic.edu.au

www.education.gov.au/school-education

www.lmip.gov.au/default.aspx?LMIP/LFR_SAFOUR/VIC_LFR_LM_UnemploymentRateTimeSeries

www.moodle.asta.edu.au

www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0

www.abs.gov.au/AUSSTATS/abs@.nsf/mf/3218.0

www.acecqa.gov.au/ministerial-standing-council-on-school-education-and-early-childhood

www.education.vic.gov.au/about/department/Pages/factsandfigures.aspx

www.education.vic.gov.au/about/programs/learningdev/vicstem/Pages/centres.aspx

www.education.vic.gov.au/school/principals/curriculum/Pages/ib.aspx

www.stav.org.au

www.study.vic.gov.au/deecd/learn/study-in-victoria/en/school-system.cfm

www.vcaa.vic.edu.au/Documents/vce/extendedinvestigation/ExtendedInvestigationSD-2014.pdf

www.vcaa.vic.edu.au/Pages/vce/index.aspx?Redirect=1

B. HALF DAY VISITS TO FOUR SECONDARY SCHOOLS ON 7 MARCH, 8 MARCH AND 9 MARCH 2016.

Roxburgh College, 60–70 Donald Cameron Drive, Melbourne.

Publicly funded school; years 7–12, approximately 1,400 students. The school has exceptionally high ethnic diversity with many recent migrants. There are 36 mother tongue languages: 50% of students are Arabic, especially Iraqi. Two-thirds of students are male. The school has a substantial Applied Learning programme as well as the general academic VCE programme.

We met six teachers, including the Head of Science, at a roundtable discussion.

We met one technician.

School contact: Principal Fernando Ianni

Penleigh and Essendon Grammar School, Rachele Road, East Keilor.

Independent fee paying school drawing on a culturally diverse part of Melbourne. K–12, organised into:

- K–6 girls' school.
- K–6 boys' school.
- 7–10 girls' school.
- 7–10 boys' school.
- 11–12 co-educational school.

Approximately 500 students in each, total 2,400.

School contact: Principal Tony Larkin

We met with the year 10 co-ordinator (who accompanied us throughout the visit), two roundtables of teachers, including the Principal, Vice-Principal and Head of Senior School; observed and spoke to students in three year 10, one year 11 and one year 12 science classes (biology, physics, and year 10 integrated topics). We toured all the secondary schools and met one technician.

Blackburn High School, 60 Springfield Road, Blackburn.

Publicly funded neighbourhood school; year 7–12. About 1,100 students.

School contact: Principal Joanna Alexander

We met with a roundtable of teachers, including Assistant Principal, Science Area Leader and Science Director of Learning. We met a roundtable of students from years 8, 9 and 11 and observed a biology lesson.

Melbourne Girls' College, Yarra Boulevard, Richmond.

Publicly funded school with a very high reputation in an affluent neighbourhood; years 7–12. About 1,300 students.

School contact: Principal Karen Money

We were shown round the school by two students, and met with a roundtable of 15 staff, including the Science Leader, who has a joint appointment at the school and the University of Melbourne. We met three students. We had a meeting with the Principal and toured the school, visiting year 7 chemistry and year 11 biology and chemistry classes.

C. A MEETING WITH PATRICK GREENE, DIRECTOR, MUSEUMS VICTORIA AND LINDA SPROAL, HEAD OF EDUCATION, ON 8 MARCH.**D. A MEETING WITH PROFESSORS RUSSELL TYTLER AND VAUGHAN PRAIN OF DEAKIN UNIVERSITY ON 9 MARCH, TO DISCUSS THE RECONCEPTUALISING MATHS AND SCIENCE TEACHER EDUCATION (REMSTEP) PROGRAMMES.****E. VISITS TO TWO SCIENCE CENTRES. THESE GOVERNMENT-FUNDED CENTRES ARE DESIGNED TO SHOW STUDENTS CUTTING-EDGE SCIENCE RESEARCH AND APPLICATIONS. TEACHERS FROM ACROSS VICTORIA BRING THEIR CLASSES TO THE CENTRES.**

- Quantum Victoria on 7 March. Centre for physical sciences. Director Soula Bennett.
- Gene Technology Access Centre (GTAC) on 9 March. Director Jacinta Duncan.

ANNEX 2: EDUCATION IN AUSTRALIA – A BRIEFING NOTE

OVERVIEW⁴

Australia has a population of 23.5 million, and Victoria a population of 5.96 million (in 2015).⁵ The majority of the population of Victoria is settled in or around Melbourne, which has a population of 4.5 million.⁶

Approximately 6% of the population is unemployed (1% lower than the OECD average),⁷ with 13% of 20-24's are unemployed. Australia sits firmly in the middle of OECD inequality rankings (0.33 – where 0 is complete equality). The spend per pupil is \$8,790 per student. The UK spends \$10,055 per student (averaged across primary through to non-tertiary education).

EDUCATION⁸

Australia has fewer underperforming students than the OECD average but, within Australia, rural and indigenous populations have lower academic performance and less access to tertiary education than their national average: students in rural schools perform 56 score points lower than students in Australian cities or large city schools.

However, the Australian education system does have a strong focus on ensuring equity, particularly with respect to Aboriginal and Torres Strait Islander populations. This can be seen through the design of curriculums.

There are two national education goals (defined in the 2008 Melbourne Declaration):

- Australian schooling promotes equity and excellence.
- All young Australians become successful learners, confident and creative individuals, and active and informed citizens.

Compared to other OECD countries, Australia's teachers have a high teaching time and students spend a lot of time under instruction.

There is a high degree of school choice in the Australian system, with many institutions competing for enrolments. It has been suggested that this level of school choice may be driving segregation of students into different schools based on their socio-economic background.

SYSTEM STRUCTURE⁹

States and Territories have a lot of autonomy over schools and Vocational Education and Training in Australia. The education system is steered nationally through a series of agreements focused on funding and education priorities. A national evaluation and assessment framework exists but there is significant local interpretation, with each territory and state having its own school improvement framework. The Council of Australian Governments (COAG) and the Education Council coordinate national educational policy.¹⁰

Children start school with a Foundation year (called a Preparatory year) age 5, and must start primary school age 6. Students then have 12 years of primary and secondary schooling. In the final two years of secondary school (upper secondary, years 11 and 12) students can study for the Senior Secondary Certificate of Education, which is required for entry to most universities and vocational training options.¹¹ Upper secondary education (Yr11+12) is not compulsory in Australia. In 2013, 84% of 25–34 year olds attained upper secondary level education – above the OECD average of 82%.

⁴ www.data.oecd.org/australia.htm

⁵ www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0 (accessed 15.07.16)

⁶ www.abs.gov.au/AUSSTATS/abs@.nsf/mf/3218.0 (accessed 15.07.16)

⁷ www.lmip.gov.au/default.aspx?LMIP/LFR_SAFOUR/VIC_LFR_LM_UnemploymentRateTimeSeries

⁸ www.oecd.org/education/EDUCATION%20POLICY%20OUTLOOK%20AUSTRALIA_EN.pdf

⁹ www.oecd.org/education/EDUCATION%20POLICY%20OUTLOOK%20AUSTRALIA_EN.pdf

¹⁰ www.acecqa.gov.au/ministerial-standing-council-on-school-education-and-early-childhood

¹¹ www.education.gov.au/school-education

Both general and vocational programmes are offered in upper secondary schools. In schools, upper secondary students can study units towards recognised Vocational Education and Training (VET) qualifications while completing their senior certificate. Vocational Education and Training (VET) in Australia is also provided at the tertiary education levels, and employers are well engaged in the system. VET facilitates entry into the labour market through; work study programmes, Technical and Further Education institutes, and private Registered Training Organisations.

Australia has the sixth highest graduation rate among OECD countries in academic programmes and the eighth highest graduation rate in vocationally oriented programmes. However, Australia is continuing to work on programmes to improve their tertiary education, particularly VET. The COAG has set VET targets to be achieved by 2020 including reaching a position where over three quarters of working age Australians have a Certificate III level qualification or higher.

The Australian Government has also set two national targets for higher education:

- Attainment: by 2025, 40% of all 25–34 year olds will have a qualification at bachelor level or higher.
- Participation: by 2020, 20% of higher education enrolments at undergraduate level will be people from low socio-economic status.

VICTORIA EDUCATION SYSTEM^{12 13}

There are over 2,200 schools in Victoria including 207 independent schools. There are four selective entry secondary schools aimed at high achievers (yr 9–12). Students apply to attend.

There are 915,159 pupils with 393,590 in secondary school. There are 41,117 teachers with 15,136 in secondary schools (Victoria State Government figures, 2015). The average class size is 21 students (the average across Australia is 24).

Education in Victoria is compulsory for children aged from 6–17 years. Students attend primary school from age 5–12 years, with the schools split into a prep class and six other year groups (years 1–6). Secondary school students are aged between 12 and 18 years old, and on rare occasions, can be up to the age of 20. Classes are divided into years 7–12.

There are four terms in the Victorian school year. School usually starts in late January or early February and runs until mid-December. There's a short holiday between terms and a long summer holiday in December and January.

Almost 25 per cent of students at Victorian schools are from language backgrounds other than English.

The school curriculum in Victoria depends on the student year level:

- Prep to year 10: AusVELS – The Australian Curriculum through the Victorian Essential Learning Standards.
- Upper secondary (years 11 and 12) – determined by the Victorian Certificate of Education (VCE).

AusVELS¹⁴ define the pre-year 10 curriculum. The eleven-level structure reflects the design of the Australian national curriculum while retaining Victorian priorities and approaches to teaching and learning.

AusVELS incorporates the Australian Curriculum learning areas for English, mathematics, history and science only, other curriculum areas are aligned with a curriculum framework originally developed solely for Victoria – the Victorian Essential Learning Standards (VELS).

There are six science strands as part of AusVELS:

- Patterns, order and organisation.
- Form and function.
- Stability and change.
- Scale and measurement.
- Matter and energy.
- Systems.

All schools also offer extra-curricular programs with many options and experiences.

ASSESSMENT

During primary and secondary school (not including upper secondary) school student assessment is a combination of the National Assessment Program Literacy and Numeracy (NAPLAN) and teacher based assessments. NAPLAN is a national assessment for students in years 3, 5, 7 and 9, that is undertaken every year in early May. It focuses solely on numeracy and literacy.

In upper secondary (years 11 and 12) students follow the two-year VCE study programme.

¹² www.study.vic.gov.au/deecd/learn/study-in-victoria/en/school-system.cfm

¹³ www.education.vic.gov.au/about/department/Pages/factsandfigures.aspx

¹⁴ www.ausvels.vcaa.vic.edu.au/

As part of the VCE students can choose from more than 90 different subjects (30 of these are vocational options). A school decides what options they offer. More advanced university level units are also offered to students to take in their final year (year 12).

Each VCE study programme is broken into four units (numbered 1,2,3 or 4). Students can study some units from unit 1,2,3 or 4 in both their first and second year of their VCE.¹⁵ Subject 'study designs' (specifications) are usually split into Units 1+2 (commonly studied in VCE year 1) and Units 3+4 (commonly studied in the second year of VCE).

To graduate the VCE students must satisfactorily complete a minimum of 16 units, three of which must be from the English group (with at least one unit from Unit 3 and 4 level), and with at least three Units 3 and 4 sequences in studies other than English. Of these 16 units, 13 can be from VET (vocational courses). Most students graduate with between 20 and 24 units.

The VCE (Baccalaureate), introduced in 2014, recognises students who choose to study both a higher level mathematics and a language in their VCE programme of study.¹⁶ It was also an incentive mechanism to drive more students to study for this combination of subjects.

One study option within the VCE programme is the 'extended investigation'. Assessment is via teacher assessment (although the task is externally determined).¹⁷

"The VCE Extended Investigation enables students to develop, refine and extend knowledge and skills in independent research and carry out an investigation that focuses on a rigorous research question. The investigation may be an extension of an area of curriculum already undertaken by the student or it may be completely independent of any other study in the student's VCE programme. Through this study, students develop their capacity to explore, justify and defend their research findings in both oral and written forms to a general, or non-specialist audience"

Victoria Assessment and Curriculum Authority (VCA),
Extended Investigation Study Design documentation

The Australian Tertiary Admission Rank (ATAR) is the scoring system used by tertiary education institutions (eg universities) to select students applying to their institutions. The ATAR score is used solely from this purpose and is derived from the VCE scores. It enables universities to compare students who have studied different subjects. Some subjects deemed more challenging will be given a higher weighting in the ATAR score. VTAC manage the process, passing on student ATAR scores and applications to selection authorities at tertiary institutions. The majority of universities use the ATAR score as part of their decision making. Some courses select up to 80% of students solely using ATAR.

ALTERNATIVE PROGRAMMES

VCAL (Victoria certificate of applied learning)

This is an alternative programme to the VCE studies in years 11 and 12. The programme includes practical work-related experience as well as literacy and numeracy skills.

VET (Vocational Education and Training)

This is a vocational programme of study followed in years 11 and 12. The programme includes workplace learning.

TEACHERS

Teaching is a graduate profession. The ratio of teachers' salaries to the earnings of tertiary educated workers is above the 2011 OECD average. Teachers have a heavy teaching workload, with more teaching time than in other OECD countries (873 hours per academic year in primary school compared to the OECD average of 790 hours). OECD data highlights the significant autonomy given to teachers in Australia compared to other jurisdictions.

During a teacher training degree, teachers have hands-on experience in schools through a supervised practicum placement programme, also known as 'teaching rounds'.

The Australian Institute for Teaching and School Leadership was created in 2010 to raise the quality of teaching and school leadership. The Institute sets standards and developed an accountability system for schools. Outputs from the accountability system are held on an Australia wide website called MySchool¹⁸ – aimed at parents and the wider community.

¹⁵ www.vcaa.vic.edu.au/Pages/vce/index.aspx?Redirect=1

¹⁶ www.education.vic.gov.au/school/principals/curriculum/Pages/ib.aspx

¹⁷ www.vcaa.vic.edu.au/Documents/vce/extendedinvestigation/ExtendedInvestigationSD-2014.pdf

¹⁸ www.oecd.org/education/EDUCATION%20POLICY%20OUTLOOK%20AUSTRALIA_EN.pdf

SCIENCE EDUCATION

Australia is ranked 10th (out of 37) in the 2012 PISA science tests.

AusVELS science (Prep – year 10)

Within the Science AusVELS, there are six overarching themes that support the coherence and developmental sequence of science knowledge within and across levels. There are three key ideas: Science Understanding, Science Inquiry Skills, and the Nature of Science.

VCE science (years 11 and 12)

Several science subjects are offered as VCEs. These include: biology, chemistry, physics, computing, health and human development, and outdoor and environmental studies. There are two options students can follow within biology, chemistry and physics.

The assessment of VCE science varies depending on the units being followed. Units 1 and 2 (usually studied in year 11) are internally assessed or as stated in official documents “a matter for school decision”. Assessment of Units 3 and 4 (usually studied in year 12) are supervised by the VCAA, however for biology the student’s achievement is also determined by school-assessed coursework.

“Percentage contributions to the study score in VCE biology are as follows:

- Unit 3 School-assessed Coursework: 16 per cent;
- Unit 4 School-assessed Coursework: 24 per cent;
- End-of-year examination: 60 per cent.”

VCAA Study Design document, Unit 3 and 4 biology

OTHER INITIATIVES OF INTEREST

Australian Teacher Education Association (ATEA)¹⁹

The Australian Teacher Education Association (ATEA) is the major professional association for teacher educators in Australia.

“The mission of the Australian Teacher Education Association is to promote:

- The pre-service and continuing education of teachers in all forms and contexts;
- The teacher education as central in the educational enterprise of the nation;
- Research on teacher education as a core endeavour.”

Science Education Technicians Association (part of ASTA, Australian Science Teachers Association)²⁰

This group aims to connect School Science Laboratory Staff across Australia, enabling them to have a voice on national issues and to share ideas across state boundaries.

Science Teachers Association Victoria (STAV)²¹

Professional association for science teachers in Victoria. Predominantly volunteer led.

Science and Mathematics Specialist Centres, Victoria²²

A system of six science and mathematics spread across Victoria, each with a different emphasis. The purpose of these centres is to give schools access to cutting edge research, equipment and experiences it is not possible to have in the classroom. The government supports school visits to the centres, with priority given to those schools in rural areas or with disadvantaged student bodies. The six centres are:

- BioLab – sport and human performance.
- Earth Ed – earth sciences and cutting edge technology.
- Ecolinc – environmental teaching.
- GTAC (gene technology access centre) – life sciences (cell and microbiology).
- Quantum Victoria – physics and maths through cutting edge technology.
- VSSEC (Victorian Space Science Education Centre) – exploring space.

¹⁹ www.atea.edu.au

²⁰ www.moodle.asta.edu.au/

²¹ www.stav.org.au/

²² www.education.vic.gov.au/about/programs/learningdev/vicstem/Pages/centres.aspx

APPENDIX 3:
COUNTRY REPORT:
FINLAND



GATSBY

I EVIDENCE GATHERING

This report has been written by Ginny Page and John Holman and is based on the following sources. Further details of the sources are in Annex 1.

- A. Desk research.
- B. Visits to three secondary schools, Viikki Teacher Training School on 20 April 2016, Helsinki Normal Lyceum on 21 April 2016 and Nöykkiö school on 22 April 2016.
- C. A dinner discussion with teachers Pekka Peura and Eeva-Lisa Nieminen on 21 April 2016.
- D. A meeting with Counsellors Anneli Rautiainen and Leo Pahkin at the Finnish Board of Education on 21 April 2016.
- E. A meeting with Professor Maija Aksela, Director of the LUMA (STEM) Centre of Finland and the LUMA (STEM) Centre at the University of Helsinki, and Director of the Unit of Chemistry Teacher Education, on 21 April 2016.

The visits were organised by Professor Jari Lavonen of the Department of Teacher Education at the University of Helsinki, and accompanied by Professor Lavonen, Janna Inkinen and Dr Arja Kaasinen. Professor Lavonen also provided individual expert advice.

2 OUTLINE OF EDUCATION IN FINLAND

This is a summary; there is further detail in Annex 2.

Finland is one of the most sparsely populated countries in the European Union, and compared to the UK, its population of 5.5 million is relatively homogeneous. Finland is recognised as a major international leader in education, consistently ranked in the top tier of countries in the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS). Attainment rates in upper secondary and tertiary education are higher than the OECD average, with one of the highest enrolment rates in upper secondary vocational education and training (VET) in OECD countries.

The fundamental administrative divisions of the country are the 313 (as of 2016) municipalities. These are relatively small authorities with a major role in governing what goes on in schools. Schools are owned by the local municipality and funded by central government and are small by English standards: in 2015, 17% of comprehensive schools had under 50 pupils and 9% had over 500 pupils. Parents may choose their child's school, but they generally go for the one that is closest, confident that it is good. Education is free at all levels up to and including university, and special needs education is provided within mainstream schools – there are no separate special schools and few private schools.

The education system in Finland comprises:

- Pre-primary (6 year olds).
- Basic compulsory education (primary and lower secondary) (7–16 year olds) in a comprehensive school.
- General academic education in upper secondary schools (about 50% of the population) for those or vocational education in vocational schools (16–19 year olds) (about 50% of the population).

Class sizes in comprehensive schools are relatively small, c.20 pupils, and there is no streaming or setting. Upper-secondary and vocational education for 16–19 year olds is flexibly organised and timetabled through the municipality to allow students to combine general with vocational learning.

The Finnish National Board of Education (NBE) is an agency of the Ministry of Education and Culture. The NBE prepares the content of the national core curricula and required teaching time, but municipalities are expected to work with their schools to devise local versions of the national curriculum. The national curriculum is reviewed every 10 years in a very consensual exercise involving parents, academics and employers. The core curricula for basic and general upper secondary education have recently been renewed and new local curricula based on this core curriculum are being prepared ready for first teaching later in 2016.

Teachers in Finland are highly trained. In lower and upper secondary education all teachers are required to hold a Master's degree in their subject, which most take alongside pedagogical training. The high level of training is seen as necessary as teachers in Finland are very autonomous professionally, and must be able to teach classes of very mixed ability in a way that supports success for all students equally. Teachers are also expected to participate in three days of state-funded in-service training every year, and many do more voluntarily.

2.1 ACCOUNTABILITY AND ASSESSMENT

There is a powerful 'culture of trust' of the teaching profession in Finland. Educational authorities and national-level educational policymakers are confident in teachers and their knowledge of how to provide the best possible education for young people. As a result, there have been no national or local school inspectors since the late 1980s, nor are there systematic evaluations of teachers.

There are no national exams for pupils in basic education in Finland. Instead, teachers are responsible for assessment in their respective subjects and courses, on the basis of the objectives included in the curriculum. The only national examination, the matriculation examination, is held at the end of general upper secondary education and is taken in four subjects in examinations of up to six hours each. Teacher assessment does not count towards the matriculation grade, although teachers do mark the matriculation exam, prior to a second marking by the matriculation board. Poor results in one exam can be compensated for by good marks in another.

The selection of students for upper secondary school is based on their grade point average for the theoretical subjects studied in basic education. Entrance and aptitude tests may also be used, and students may be awarded points for hobbies and other relevant activities. Commonly, admission to higher education is based on the results in the matriculation examination and university entrance tests.

Teachers are trusted to deliver reliable assessments, and schools are trusted to maintain the expected standards. There are no league tables and there is no system of external inspection – though there are regular evaluation visits by school supervisors from the municipality. School performance data is not published by government, although various media sources do collate and publish such data.

The education system is monitored through a process of regular, national sampling where around 10% of schools administer tests to their year 6 and 9 students in Finnish and literature or mathematics. The results are made available to the school and to the municipality for development purposes, and are also correlated with teacher grades to check that internal assessments are effective.

3 SCIENCE EDUCATION IN FINLAND

3.1 STEM

The government has prioritised STEM over the past 20 years through a major investment in LUMA, a national project to improve skills in mathematics and natural sciences. LUMA Centre Finland was established 8 November 2013, as the umbrella organization for LUMA Centres in Finnish Universities, to strengthen and promote their collaboration on national and international level. The LUMA Centre Finland network is directed and coordinated from the University of Helsinki. The LUMA Centre at the University of Helsinki includes seven so-called resource centres: BioPoP (biology), Geopiste (geoscience), F2k (physics), Kemma (chemistry), Linkki (computer science), LumO (pedagogy) and Summamutikka (mathematics). Activities include:

- Science clubs, camps, events, webzines and other activities for children and youth.
- Pre-service and in-service training for teachers, and interactive online web portals including videos and other materials as well as science classes and laboratories that support teachers in their work.
- Research on the teaching of mathematics and natural sciences and on the effectiveness of LUMA's own activities, and the development of them based on the research results.
- Collaboration with decision-makers and media, and especially with other active partners in the field.

3.2 SCIENCE IN THE SCHOOL CURRICULUM

The national curriculum in Finland is revised every 10 years, in a very consensual exercise involving parents, academics, employers and text book publishers. The Finnish National Board of Education (NBE) determines the core curriculum and the lesson hours associated with different aspects, but it is for municipalities and schools to make their own version and the potential for variation is significant. As part of this process of local curriculum development, teachers are encouraged to analyse key education questions, such as:

- What will education mean in the future and how can education prepare young people to the future?
- What types of competences will be needed in everyday and working-life situations?
- What kind of learning environments and practices or teaching methods would best produce the desired education and learning?

In August 2016 a new curriculum comes into force in Finnish schools. Some key changes are:

- A focus on seven generic competences and 21st century competences.
- At least one cross-curricular project each year.
- More collaborative classroom practices and project work.
- More teacher autonomy but also 'more responsibility for teachers'.
- An emphasis on the role of technology in teaching and learning.
- Emphasis on formative assessment for learning.

Despite some interpretation that these reforms meant the end to subjects in the Finnish curriculum, the Head of Curriculum Development at the Finnish National Board of Education has said: "Traditional school subjects will live on, though with less distinct borderlines and with more collaboration in practice between them". All students will continue to study some science all the way through, from basic education to the end of upper secondary. Science is taught as separate subjects – physics, chemistry and biology – and by specialist teachers who hold a major and a minor specialism. However, unlike England, biology is traditionally more closely associated with geography than with physics and chemistry.

Courses are generally taught to small groups of about 20 pupils over 6-week periods in lessons of at least 45 minutes (commonly 75 minutes). The Finnish curriculum is therefore comprised of many intense, short courses – some compulsory, some optional – over which teachers have significant autonomy in terms of content, pedagogy and assessment.

3.3 SCIENCE TEACHERS

Teachers in Finland are highly trained. In general education, all teachers are required to have a Master's degree and specialise in a major and minor subject. Biology and geography are frequently associated in this way, though a maths specialism generally gives the teacher more employment opportunities, as maths teachers are always in demand. In vocational education teachers should have a Master's degree or Bachelor's degree. The high level of training is seen as necessary, as teachers in Finland are very autonomous professionally.

Teacher training can be either concurrent, with pedagogical training integrated into the Master's programme (85% of students take this route), or consecutive, with the pedagogical training completed over one year after the initial degree. The consecutive model also serves those who decide on a teaching career later. This means that secondary school teacher training effectively takes five years. There are no national exams or standards involved in becoming a teacher.

However, according to the general national- and university-level strategies, teacher education should be based on scientific research and professional practices in the field and provide students with the knowledge and skills needed to operate independently as an academic professional and developer in their field. Specifically, teacher education programmes should include a high level of scientific knowledge and knowledge about general and science-specific pedagogies, as well as an understanding about the role a school plays in society and the skills teachers need to collaborate with other teachers and others in their wider communities. They must also develop skills in communication, ICT, academic research, curriculum planning and professional development.

Teachers can train at one of eight universities throughout Finland and every student teacher participates in teaching practice at a university teacher training school. In these schools, pupils may have up to half their lessons taught by a trainee teacher. In-school teaching practice constitutes around 25% of a teacher's traineeship. The teacher training schools belong to the universities' faculties of education but aim to retain strong links to the faculties of science as well. Teacher training is very competitive and universities are able to select from the top 25% of the cohort.

3.4 SCIENCE BEYOND THE SCHOOL CURRICULUM

The government has prioritised STEM over the past 20 years through a major investment in LUMA, a national project to improve skills in mathematics and natural sciences. It was suggested that this has been successful in terms of recruiting students to science and engineering courses at university, though perhaps less so for mathematics and physics. LUMA Centre Finland was established 8 November 2013 as the umbrella organisation for LUMA Centres in Finnish Universities to strengthen and promote their collaboration on national and international level. The LUMA Centre Finland network is directed and coordinated from the University of Helsinki.

4 RELEVANT FINDINGS

4.1 TYPES OF PRACTICAL SCIENCE

In the schools we visited, practical activities were relatively short (20–30 minutes) and straightforward. Most lessons were 75 minutes long, giving time for a short introduction to the ideas and the activity and for plenty of discussion afterwards. The discussion period was sometimes compromised, however, by the time taken by students and teacher to clear up after the practical.

Class size varied from 10 to 23, but was 15 on average among the grade 7–10 classes that we visited. Practical work was conducted in groups or in pairs and there was almost always more than one teacher, or trainee, in the classroom. In one class at Viikki school, additional support was provided in a grade 8 physics lesson by a special needs teacher who was primarily focused on two students in the room and helped them to keep pace with their partner in a practical activity on velocity.

The student:teacher ratio was crucial in enabling a significant amount of interaction during the practical. This was important, as sometimes relatively little introduction was given and students would embark on the activity with a limited understanding of why they were doing it. Groups involving more able students would work this out during the course of the activity, talking to each other and referring to the worksheets they were given. Struggling groups were quickly spotted by circulating teachers and prompted through discussion to consider the ideas behind the practical, and identify any misconceptions. This rarely seemed to cause students concern – one grade 9 biology student at Nöykkiö School cheerfully told us: “We learn best by doing, even when we make mistakes. And we always make mistakes”. Teachers are exceptionally focused on the pupils in their class and on their individual needs during the lesson.

At Nöykkiö School, the Principal is trialling the separation of male and female students for grade 9 chemistry (and sport). We visited when the two groups were doing a practical to identify the presence of starch using iodine. The groups were of equal size but of differing energy levels, so timetabling the lesson concurrently in adjoining laboratories meant the three teachers involved could move between labs and be deployed where the need was greatest.

While we were told that group work was often a necessity as schools did not have sufficient equipment for pairs or individual working, a physics teacher told us that Nöykkiö School attempts to keep group size small in physics and chemistry to enable better student engagement with practicals. This didn't seem to be such a priority for biology in any of the schools we visited, where class sizes were bigger and practicals were less experimental. A biology teacher (and PhD geneticist) at Helsinki Normal Lyceum told us that even if she had the equipment in school for students to undertake real gene sequencing, she would prefer her method of using paper models as it enabled more time for discussing the concepts involved. Instead, she takes her grade 9 students to the LUMA Centre at the University of Helsinki to undertake gel electrophoresis using modern kit.

4.2 HOW FREQUENTLY?

In both Viikki and Helsinki Normal Lyceum, we were told that physics and chemistry teachers aimed at 100% of their lessons involving a practical. This may have been made easier due to their role as teacher training schools and hence with a plentiful supply of trainees to assist during practicals. But it was clear that the teachers believed in the absolute integration of practical work into science teaching and learning – in the schools we visited, hands-on meant minds-on. However, the proportion of practical lessons was estimated to drop to about 50% in biology, and generally decreased as students neared their matriculation exam at the end of upper secondary schooling.

Despite science lessons being predominantly practical, the simplicity of the activities meant that specialist laboratory space was not always necessary. In fact, labs appeared to be occupied between 45% and 65% of the time, and were often only half-full.

4.3 ATTITUDES TO PRACTICAL SCIENCE

We found the teachers we spoke to uniformly supportive of practical work as a method of engaging the minds of their students. This was particularly true of physics and chemistry teachers who routinely used practicals to give a ‘real life’ aspect to abstract or difficult concepts, and who found that practicals kept their students motivated to learn by engaging through a hands-on activity. There was a sense from teachers that complex investigations and/or equipment presented a barrier to this process and could inhibit the engagement.

A physics/chemistry teacher at Viikki School told us that her ideal practical would: “Be straightforward in terms of student understanding; use simple kit; be equally doable by all students independently; but also give results which had meaning and could be discussed within a group of students”.

We asked the teachers we met why they chose to do so much practical work, and we were told it was in part due to the success of introducing more practical work in primary science. It was not clear whether increasing practical at secondary level had similar positive impacts. However teachers had a great deal of freedom about their choice of curriculum and pedagogy, were given a lot of trust by the authorities and their Principal, and only felt accountable to students and parents. Teachers could use their professional judgement to decide whether a particular approach was working, and adjust it wherever necessary. Therefore it's reasonable to assume that what we observed was successful, at least in terms of that particular school.

It was clear in all the schools we visited that the attitudes and motivations of biology teachers were different to physics and chemistry. This was in part because of a longstanding tradition whereby a significant number of biology teachers also specialise in geography (whereas chemistry teachers will often have physics as their other specialism). It was perhaps unsurprising then that we were told that fieldwork was quite common, particularly in Nöykkiö School, which is surrounded by forest, and where all grade 8 students undertake small studies in local ecology through 3 x 3 hour field trips over the course of a year.

4.4 FACILITIES AND FUNDING

In all the schools we visited, the laboratories were generally spacious (and rarely more than two thirds full) but were fairly basic when compared to counterparts in England. Gas, electricity and water were mostly available only at the side of the laboratory, and often with sufficient access for group work but not paired or individual practicals. Instead of using a central gas supply, Nöykkiö School used camping gas Bunsen Burners in their chemistry laboratories. At another school, we were told that students watched YouTube videos of bacterial growth because it was not possible for them to create bacterial plates in their own labs.

Similar to the joint specialisms of the teachers, the physics and chemistry department was separate from the biology and geography department in the schools we visited, and the laboratories in each department tended to serve both subjects rather than be specific to one science. Not only did this keep biology teachers at one remove from their physics and chemistry colleagues, it also presented some logistical issues if biology teachers wanted to use chemistry consumables or equipment in their laboratories.

We saw quite limited amounts of equipment – less than a class set of microscopes in one school – and broken equipment which the teachers did not have the time or skill to fix (with one fume cupboard being used as storage). Prep rooms were of variable size and tidiness, but much of the equipment was kept in the laboratories where students would take responsibility for collecting it, cleaning it and tidying it away.

In the schools we visited, IT was in common and effective usage, though often limited to quite basic applications such as visualisers to cover the theoretical part of science lessons. At Nöykkiö School, we also observed a grade 9 biology lesson where students filmed their dissection of a heart on an iPad, then edited their film with subtitles and music and uploaded it to the schools' learning platform (WILMA) before the end of the lesson. We were told that WILMA is used by students to keep all their work in one place, by parents to monitor their children's progress, and by teachers to assess their students' achievements.

4.5 TECHNICAL SUPPORT

None of the schools we visited employed science technicians and we were told that this was the situation throughout Finland. But in acknowledgement of the significant time that science teachers spend preparing for practicals and clearing up after them, they all receive an additional payment (which translates as a 'demonstration extra') on top of their normal salary. This is regulated through a national agreement, and works out at 20% of a physics/chemistry teacher salary and 5% for a biology teacher. This payment recognises the number of hours that a science teacher might otherwise spend on non-teaching activities such as preparing experiments, and the constraints placed on science teachers who might otherwise have more freedom about how many hours they want to teach in a week (upwards from a minimum of around 20 per week).

In addition to the 'demonstration extra', most schools pay extra to one or two science teachers for taking responsibility to order chemicals and equipment, organise the equipment storage and so on. The amount of this payment varies from school to school. In Viikki School, they pay about 16 hours per year to one physics teacher, and the same to one chemistry teacher.

4.6 PROJECT WORK

The schools we visited did quite varying amounts of project work as part of their science courses, though the teachers were aware that the new national curriculum required the introduction of interdisciplinary projects across the school. Helsinki Normal Lyceum did relatively little project work, similar to Viikki Teacher Training School where teachers were considering a new problem-based learning approach in science inspired by work undertaken by Michigan State University in the USA.

At Nöykkiö School, teachers focused project work on students selected for entry into grade 7 on the basis of their interest and aptitude in STEM, and were entitled to take a special STEM course, which was largely delivered in English. We received presentations from a group of such students who the year before had researched a variety of topics, from how plant growth changes with the direction of light, to the factors affecting climate change, to shifts in local forest ecology. They told us they liked practical work because it was intrinsically interesting, made concepts easier to remember, gave them the chance to “do something different than read a book, and enabled them to “make something happen”.

It was very rare for students to undertake independent investigations, and it was relatively uncommon for them to be asked to plan their own experiments.

4.7 ASSESSMENT OF PRACTICAL SCIENCE

We heard very little from either teachers or students about the impacts of external assessment on practical science. For the teachers we spoke to, practical work was a means to achieve a stronger engagement with, and therefore understanding of, scientific knowledge. Therefore, the results would be evident in the choices students made to continue with science post-16, and in the results of their matriculation exam at 18.

Assessment in laboratories was mostly formative, and students were encouraged to self-assess where appropriate. For one physics/maths teacher, the best learning comes when his students take complete responsibility for their own assessment to the point of awarding themselves their own final course grade. This process involves continual reflection about what they understand, with his role being to guide them in ways to gain the knowledge and skills they self-identify as lacking.

However, teachers were expected to grade courses (and this expectation is likely to increase with the new curriculum), and these grades are important in determining which upper secondary school a 16 year old might enter. At Nöykkiö School, a physics/chemistry teacher designs simple summative tests for his courses, tweaking them each year to ensure variation between year groups. He told us he preferred not to assess directly through practical work because of the likelihood of unexpected incidents, but the tests he creates are based on the practicals the students have recently undertaken, giving him confidence that they can draw on the experience when sitting the test. He and his colleagues also use Fronter (a commercially available digital teaching and learning platform) to construct simple online tests, which the students seem to enjoy taking, and can even construct themselves.

At Helsinki Normal Lyceum, one physics/chemistry teacher gives all her grade 9 students a written report assessing how ‘active’ they had been in their practical work, and how well they had participated in discussions around experiments. She encourages her students to grade themselves as well, and if it differs from the grade she gave them she is open to negotiation, though this rarely happens.

4.8 TEACHERS’ TRAINING AND CPD

The teachers we spoke to were passionate about the subjects that they taught, and confident about the way they taught them. We had heard much about the high status of Finnish teachers, and we asked teachers at Nöykkiö School where they felt that status came from. Their experience was not that the status was externally given to them – they are not paid significantly more than other professions – but that their judgement was not externally questioned either. There were not criticised or held to account by anyone other than students and parents, who they felt had a right to question their approaches, and who could be engaged in discussion if there were disagreements.

Being given so much autonomy relies on high quality training and development. As well as the length and integration of teacher training with Masters level science courses, what we observed in the schools we visited was the extent to which trainees were engaged in feedback discussion during their teaching practice. We heard it was common for trainees to have up to 10 'observers' sit in the back of a classroom and afterwards offer constructive comment on their lesson. More commonly, a trainee has the chance to reflect on their practice with an experienced teacher/mentor and three or four other science teacher trainees who sit in on their lessons. This culture of openness, as well as a willingness to engage with criticism and learn from others, felt very integral to the process of professional formation, and clearly enabled trainees to learn swiftly what they might do differently or better next time.

The LUMA (abbreviated from "luonnontieteet", the Finnish word for natural sciences, and "mathematics") programme – initially led by the Finnish Government but transferred to the University of Helsinki in 2003 – is credited with catalysing a positive change in primary teachers' attitudes to science and maths, but also with strengthening the professional development of secondary STEM teachers in terms of practical work. Combining research and development in teacher education, informal learning, and curriculum enrichment, the programme now has 13 regional centres based in universities around Finland, with the University of Helsinki taking a co-ordinating role. We were told by Professor Maika Aksela, Director of this network, about the importance of linking initial and continuing teacher education, of connecting informal and formal learning experiences in science for young people, and of close partnerships between science and education departments at Finnish universities.

At the University of Helsinki, for example, chemistry, physics and mathematics teacher training now starts in the students' second year where they can take a number of education courses within their science departments as an integrated part of their degree. Generous funding from the Finnish Government enables the LUMA network to develop and disseminate new models for teaching the sciences, maths and technology, and to offer 'real science' experiences for young people as part of professional development for teachers.

We heard very little directly from the science teachers we spoke to about formal CPD. It appeared that municipalities were responsible for co-ordinating and commissioning professional development, but the importance of this for science teachers was unclear.

5 EMERGING LESSONS FOR ENGLAND

The high quality of practical science in Finnish schools is related to the high level of training of teachers, because good specialist knowledge brings confidence in practical scientific situations. The level to which Finland's science teachers are trained is partly a result of close integration between science and education departments in universities over the course of a 5-year training programme. While England is unlikely to extend its period of teacher training, there is no reason why greater recognition and co-operation between science and education departments cannot start during undergraduate degrees and extend into PGCE, effectively lengthening the period of initial teacher formation. This might be something to consider trying out in a pilot.

Universities in Finland work in close partnership with schools designated as Teacher Training Schools. One particular advantage this gives is the opportunity for groups of trainees to learn together and form a very effective community of developing practice, observing each other's lessons, sharing ideas and giving constructive feedback. For the school, the benefit of having so many adults available to assist in science lessons could outweigh the disadvantages of investing in training teachers who may go on to teach elsewhere. Changes to teacher training in England have in many cases driven an unhelpful wedge between universities and schools which adopting the Finnish model could redress, as well as creating better trained teachers.

Finnish schools show that less can be more when it comes to practicals – use of short, simple (20–30 minute) practicals appeared successful in enabling students to understand concepts, and the high frequency of practicals meant that they were confident in their laboratories and adept in technical skills. Several teachers told us they try to do some practical work in every lesson, whether they were experienced or new teachers. One teacher said: “I can’t imagine a lesson in which I did not do practical work of some kind”. In order for this to be effective, lessons needed to be long enough to enable plenty of discussion afterwards, and relied on small classes often with more than one teacher to circulate among students as they worked through their practical with relatively little scaffolding from worksheets. Teachers are intensely focused on their students and their needs. With more timetabling freedoms there is the potential for more schools in England try out new ways of structuring their science courses, particularly at Key Stage 3, to accommodate this sort of approach.

For older, post-16 science students, exposure to more complicated equipment and the opportunity to undertake investigations could be gained outside the school by visiting a LUMA Centre. This had the advantage of delivering activities that are supposed to give the student the chance to behave like a ‘real scientist’ in a real science environment. We can see that universities and science centres in England could do more to explicitly offer these experiences to schools, though as we didn’t visit any truly rural schools in Finland we weren’t clear if the opportunities were equally available to those who lived some distance from a LUMA Centre.

The financial costs of not having science technicians were high; with science teachers paid at least 20% more on top of their normal salary. It would be worth Finland considering the savings they might make in their salary budget if they adopted the UK model of employing science technicians in schools. There were time costs too, with teachers using lesson time to help students clear up. One benefit was how habitually students collected equipment, cleaned it and tidied it away before the end of the lesson. This kind of responsible and efficient behaviour in the science lab is something that universities and employers in England have said they would like to see more of among school leavers.

The attitude to health and safety during practical lessons was mature and proportionate (generally). This may be a result of the pervasive culture of personal responsibility among Finnish teachers and students. But our impression was that schools in Finland may choose for students to conduct riskier practicals in a local university or science centre where there were facilities and staff to manage that risk. There are persistent claims that many schools in England, despite the presence of technicians and availability of advisory services, are placing unnecessary constraints on practical work due to concerns about risk. Exploring these claims and, where legitimate, the reasons behind them might inform strategies to develop proportionate approaches to risk management in practical science.

It was hard to know if the predominance of group work in practical science in Finland was a deliberate pedagogic choice or a result of limited equipment caused by modest budgets. Either way, it was an approach which worked well in mixed ability classes, and we saw plenty of examples of students helping each other work out what they were doing, and explain it to each other. This not only maximised learning: it was an important part of collaborative working in science and it may be that the removal of assessed coursework in science GCSEs and A levels provides an opportunity for schools in England to use group work more frequently and constructively.

As in other countries we have visited, there was less practical work going on in biology than in physics and chemistry. This is clearly indicated in the differences between the additional payments due to practical work made to physics and chemistry teachers (20%) compared to biology teachers (5%). One reason may be a strong tradition of dividing physics and chemistry from biology and geography, whether in teacher training or in the arrangement of departments in laboratories in schools. Some in England have suggested that biology has more in common with geography than physics, and Finland presents some warning about what could happen if this association was followed through into teacher training and/or curriculum development.

The absence of any external assessment before 18, or any external inspection of schools, clearly frees science teachers in Finland to teach and assess in a way they feel gets the best results for their students, whether or not that is measurable in terms of the matriculation exam. While teachers in England might feel that such a model is unthinkable among our policymakers, it is inevitable that many teachers themselves find it difficult to imagine ‘success’ in other terms because they have been both student and teacher in a system with very strict accountability measures. Encouraging teachers early and throughout their career to think deeply about what success means for them, in their classrooms and their laboratories, and to share this with colleagues, may seem like an obvious step but we think it may be one too infrequently taken.

The new national curriculum in Finland will require schools to introduce a cross-curricular project for each year group. Yet the lack of prescription from the Finnish National Board of Education about the nature of such a project has left some teachers feeling a bit mystified about what they are supposed to be doing. However, the fact that everyone is aware the curriculum won't be changed again for 10 years means there is plenty of time for teachers to develop strategies to deliver these projects, and to improve them over time. Politicians in England might consider that a longer reform cycle might allow for a less prescriptive curriculum.

Teachers in Finland do work long hours and are not highly paid, but the professional status they gain through their training and are accorded through the lack of external scrutiny means they choose to be committed to tasks they believe in, rather than feel obliged to do something they don't necessarily agree with. This autonomy means science teachers can make decisions about what they teach, and how they teach it, and under the new curriculum it is planned for levels of teacher autonomy to increase. Both Finland and England intend that their very different approaches to accountability are about ensuring higher quality teaching and learning. Further work looking at the relationships between science teacher autonomy, effectiveness, and accountability in these and other countries might suggest a new, more constructive model for implementation in England.

ANNEX I: SOURCES OF EVIDENCE

A. DESK RESEARCH.

Main sources (accessed April 2016)

www.en.wikipedia.org/wiki/Finland

www.webgate.ec.europa.eu/fpfis/mwikis/eurydice/index.php/Finland:Overview

www.data.oecd.org/finland.htm

www.oecdbetterlifeindex.org/countries/finland/

www.localfinland.fi/en/statistics/Pages/default.aspx

www.oecd.org/eco/surveys/Overview_Finland_2014.pdf

www.oph.fi/download/175020_education_in_Finland.pdf

www.stat.fi/til/kjarj/2015/kjarj_2015_2016-02-11_tie_001_en.html

www.pasisahlberg.com/wp-content/uploads/2013/01/OECD-Finland-Lessons-for-Japan-2012.pdf

www.keepeek.com/Digital-Asset-Management/oecd/education/education-at-a-glance-2015/european-union_eag-2015-54-en#page1

www.oph.fi/english/education_system

www.oph.fi/download/151294_ops2016_curriculum_reform_in_finland.pdf

www.oph.fi/download/144754_Education_training_and_demand_for_labour_in_Finland_by_2025_2.pdf

www.minedu.fi/OPM/Verkkouutiset/2015/03/curricula.html?lang=en

www.oph.fi/english/current_issues/101/0/what_is_going_on_in_finland_curriculum_reform_2016

www.minedu.fi/export/sites/default/OPM/Julkaisut/2006/liitteet/eng_opm15.pdf

www.oph.fi/download/148966_Quality_assurance_in_general_education.pdf

www.enorssi.fi/ftts/about-us-1

www.webgate.ec.europa.eu/fpfis/mwikis/eurydice/index.php/Finland:Teaching_and_Learning_in_General_Upper_Secondary_Education

www.minedu.fi/OPM/Tiedotteet/2013/12/pisa.html?lang=en

B. HALF DAY VISITS TO SECONDARY SCHOOLS ON 20 APRIL, 21 APRIL AND 22 APRIL 2016.

Viikki Teacher Training School, Kevätkatu 2, 00790 Helsinki, Finland

Viikki School is part of the University of Helsinki and is one of the oldest Finnish schools, dating back to 1869. In 2003 the school moved into a new building, offering a modern environment for high quality, innovative teacher training as well as schooling for elementary pupils through to upper secondary students. The school has about 400 pre-school pupils, 500 7–19 year old students, 100 teachers, and at any time be hosting up to 250 teacher trainees. Post-16 entry is very competitive – only 15 out of 100 grade 9 students continue into upper secondary education here.

We observed and spoke to teachers, trainee teachers and students in a grade 8 physics class, and a grade 9 physics class. We also met with the Vice-Principal, school counsellor, and a physics/chemistry teacher.

School contact: Vice-Principal Marja Martikainen

Helsinki Normal Lyceum, Ratakatu 6, 00120 Helsinki, Finland

Helsinki Normal Lyceum is part of the University of Helsinki and provides comprehensive education for 12–16 year olds (currently 290 pupils) and upper secondary education (245 pupils). Established in 1867, it is considered one of the most prestigious schools in Finland. Pupils come from the surrounding area, but 25% are selected on the basis of test for Latin.

We observed and spoke to teachers and students in a grade 10 physics class, a grade 8 chemistry class, a grade 8 physics class, a grade 8 biology class and a grade 7 biology class. We also met with a physics/chemistry teacher and a biology teacher.

Nöykkiö School, Espoo, Finland

Nöykkiö School is a middle school for 450 grade 7–9 students in the Espoo region, bordering on Helsinki. While students come from the local area, the school also recruits around 24 students via an aptitude test into a special project-based STEM course taught in English. A group of these students, now in grade 8, gave presentations to us in English about the projects they had conducted the year before, and discussed with us their feelings about practical work.

We observed and spoke to teachers and students in a grade 8 biology class, a grade 9 chemistry class (split into two separate groups by gender), and a grade 9 biology class. We also met with a physics teacher and a biology/geography teacher.

ANNEX 2: EDUCATION IN FINLAND – A BRIEFING NOTE

ABOUT FINLAND

Finland's population of 5.5 million is scattered across a country of lakes and forests, with a population density of 18 people per square kilometre, making it one of the most sparsely populated in the European Union. The fundamental administrative divisions of the country are the 313 (as of 2016) municipalities; relatively small authorities which together provide a large share of public services, including education, health care and social services. Spending has increased steadily in recent years, financed by municipal income tax, state subsidies, and other revenue, and some municipalities are struggling to align service provision with national standards.

Compared with the UK, the population is relatively homogeneous in terms of language and ethnic background, though immigration rates are increasing. Finland has one of the world's most extensive welfare systems, and performs well in many measures of well-being relative to most other countries in the OECD's Better Life Index, ranking at the top in education and skills, and above average in environmental quality, subjective well-being, personal security, social connections, civic engagement, housing and work-life balance. The challenge now is to maintain these standards in the face of a weakening economy.

THE FINNISH EDUCATION SYSTEM

Finland is recognised as a major international leader in education, consistently ranked in the top tier of countries in Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study. This has drawn significant attention from other countries hoping to learn from Finland's success (though it bears noting that its performance in PISA is not due to high achievers being exceptionally high, but because of the small gap between the low and the high achievers). Key aspects of the Finnish system include:

- Freedom to teach without the constraints of standardised curricula and the pressure of standardised testing.
- Teachers educated at least to Master's level including educational theory with time each week dedicated to professional development.
- Self-evaluation by education providers coupled with regular national tests in Finnish and literature or mathematics in Years 6 and 9 in a sample of c. 10% of schools.

The education system in Finland comprises: pre-primary (six year olds); basic education (7–16 year olds); and then two pathways which are inter-linked – vocational pathways leading to a polytechnic degree, and general upper secondary education leading to a university degree, a master's degree then doctoral study. Basic education is compulsory after which pupils have the choice to:

- Move into upper-secondary/high school (51% in 2013).
- Move to vocational schools (40%).
- Pursue other studies (3%).
- Do not continue immediately (9%).

In Finland there is a strong belief in the impact that quality of education¹ has on the employability of young people and long-term unemployment.² Hence developments in basic, upper secondary and vocational education, and courses at universities and applied universities are aimed at improving the competitiveness of the economy and employment rate. Examples of the success of the policy include:

- In 2015, 92% of students continued in upper secondary or vocational education.
- The Early School Leaving (ESL) rate students in Finland was 9% in 2015³ and is below the Europe 2020 target 10%⁴ (18–24 years old).
- 46% of 30–34 years old have completed a university-level qualification.⁵ This is higher than the EU 2020 target (40%).

Attainment rates in upper secondary and tertiary education are higher than the OECD average, with one of the highest enrolment rates in upper secondary vocational education and training (VET) in OECD countries. School dropout is lower in Finland than in other EU countries, and is higher among people with an immigrant background. Adults (16–65 year olds) in Finland scored among the top skilled across participating countries in the Survey of Adult Skills, with younger adults (16–24 year olds) scoring higher than all adults in Finland and young adults in other countries. In the context of the economic downturn, unemployment remains below OECD average.

The Finnish Government envisages that at least 42% of 30–34 year olds will hold a higher education degree and that more than 90% of 20–24 year olds will hold a post-compulsory qualification by 2020.

Upper-secondary and vocational studies are flexibly organised and timetabled through the municipality to allow pupils to optimise their subject choices and, if they want, they can combine upper-secondary (often known as high school), with vocational learning. In order to make this possible, the schools organise their training provision in standard six-week modules. The general age to take upper secondary studies is from 16–19 years. However, many students are older, especially in vocational education.

Education is free at all levels up to and including university, including free school meals (which most pupils take up), free pupil welfare services, and free transport to and from school in basic education for those pupils who need it. Special needs education is provided within mainstream schools – there are no separate special schools. There is a tradition of participation in adult education and extensive provision for it.

Schools are owned by the local municipality and funded by central government and are small by English standards: in 2015, 17% of comprehensive schools had under 50 pupils and 9% had over 500 pupils. Parents may choose their child's school, but they generally go for the one that is closest – although there are some schools that offer a specialism in, for example, sport, and where there would be some kind of selection process.

¹ Berger, N. & Fisher, P. *A well-educated workforce is key to state prosperity* (2013). Economic Analysis and Research Network (EARN). Washington: Economic Policy Institute www.epi.org/publication/states-education-productivity-growth-foundations

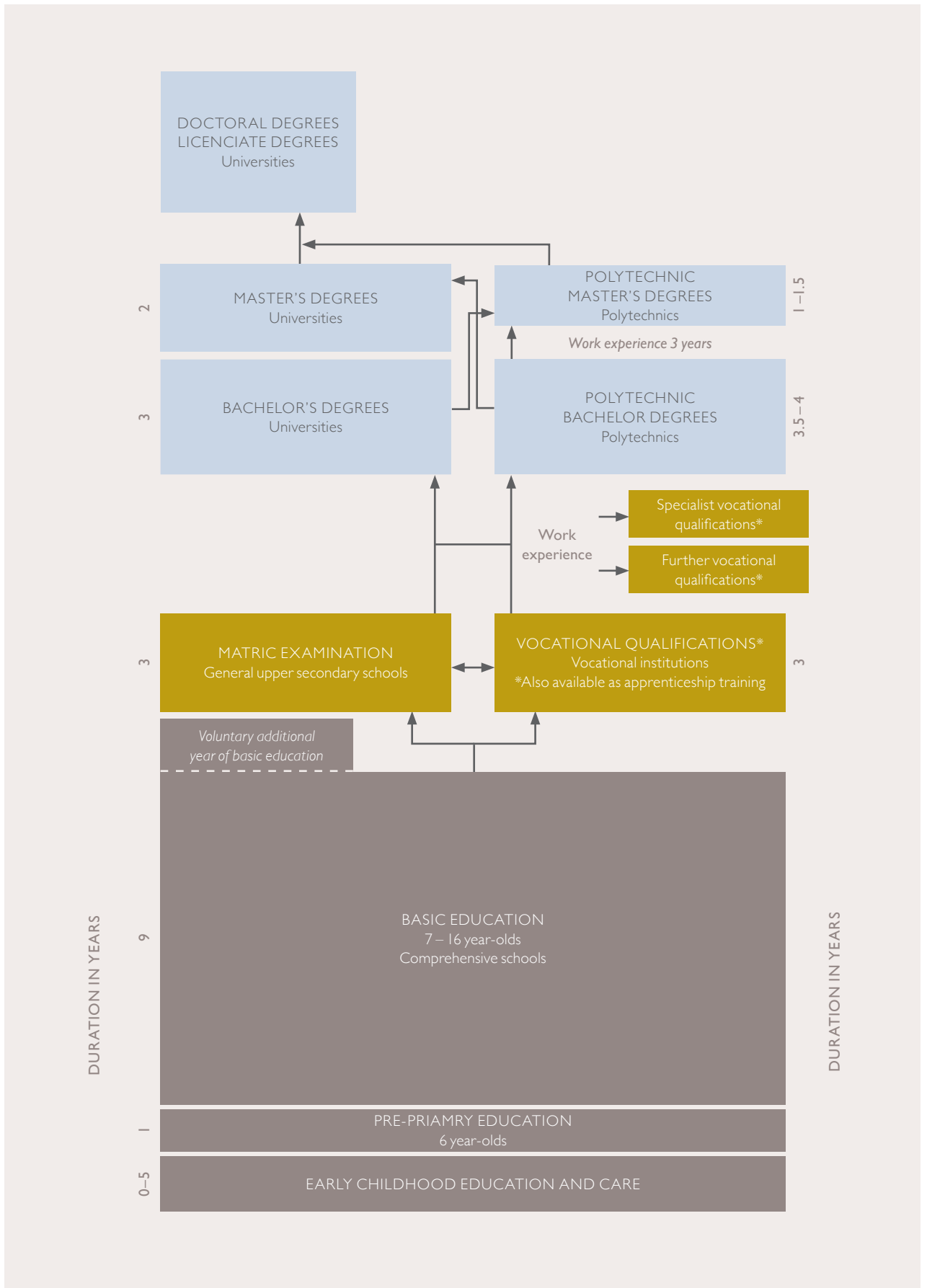
² Statistics Finland (2013). High level of education protects against unemployment. Source: Employment Statistics, Statistics Finland www.stat.fi/til/tyokay/2012/02/tyokay_2012_02_2013-06-05_tie_001_en.html

³ Alueelliset koulutustilastot www.ec.europa.eu/eurostat/statistics-explained/index.php/Education_statistics_at_regional_level/fi Early leavers from education and training of 18–24 year students www.appssso.eurostat.ec.europa.eu/nui/show.do

⁴ Cederberg M., & Hartsmar N. *Some Aspects of Early School Leaving in Sweden, Denmark, Norway and Finland* (2013) *European Journal of Education*, 48(3).

⁵ Eurostat (2016) Europe 2020 education indicators in 2015 www.appssso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

Figure 1: Education system in Finland



CURRICULUM AND ASSESSMENT

There are no national tests for pupils in basic education in Finland. Instead, teachers are responsible for assessment in their respective subjects on the basis of the objectives included in the curriculum. The only national examination, the matriculation examination, is held at the end of general upper secondary education. The selection of students for upper secondary school is based on their grade point average for the theoretical subjects in the basic education certificate. Entrance and aptitude tests may also be used, and students may be awarded points for hobbies and other relevant activities. Commonly, admission to higher education is based on the results in the matriculation examination and entrance tests.

The Finnish National Board of Education (NBE) is an agency of the Ministry of Education and Culture. The NBE prepares the content of the national core curricula and is in charge of the national joint application system for upper-secondary level education. The national core curriculum lays down curriculum content and required teaching time, but municipalities are expected to work with their schools to tailor its delivery, and teachers have considerable autonomy. The core curricula for basic and general upper secondary have recently been renewed and new local curricula that are based on this core curriculum should be prepared by the beginning of school year 2016–2017.

The new national level curricula emphasise learning of: competences such as ways of thinking, working, tools for working, contexts and attitude; employability; new pedagogy, new learning environments; and digitalisation of education. There are also new guidelines for inclusion and counselling in order to prevent early school leaving, drop out of young people from the society and unemployment.

The national core curriculum and the distribution of lesson hours for subjects are determined by the Finnish National Board of Education. It includes the objectives and core contents of different subjects, as well as the principles of pupil assessment, special-needs education, pupil welfare and educational guidance. The principles of a good learning environment, working approaches, and the concept of learning are also addressed in the core curriculum.

Recently, the government have also produced a separate curriculum aimed at immigrants and foreign language speakers in order to provide them with the linguistic and other capabilities required for the transfer to general upper secondary education.

The education providers, usually the local education authorities and the schools themselves, draw up their own curricula for pre-primary and basic education within the framework of the national core curriculum. These curricula may be prepared for individual municipalities or institutions or include both sections.

Apart from the matriculation examinations, assessment is done entirely by teachers. The NBE also produces national anticipation data on demand for labour and educational needs in support of decision-making. In addition, the Board supports regional anticipation efforts carried out under the supervision of regional councils. It obtains statistics and produces tools required for anticipation as well as estimates of labour demand and educational needs for regional councils in co-operation with regional councils, the Ministry of Employment and the Economy and the Government Institute for Economic Research (VATT).

Teachers are trusted to deliver reliable assessments, and schools are trusted to maintain the expected standards. There are no league tables and no system of external inspection – though there are regular evaluation visits by school supervisors from the municipality. School performance data is not published by the government although various media sources do collate and publish such data. To support teachers in the assessment, the core curriculum provides the criteria for good performance for assessment at the end of grade six and the final assessment in grade nine.

Upper-secondary pupils have to take a minimum of 75 courses over two to four years, which must include English, mathematics and mother tongue (Finnish or Swedish). Each course comprises three 75-minute lessons per week for six or seven weeks. At the end of their time in the school, pupils receive a diploma which sets out what they have studied; they also have to take matriculation exams which are the only external school exams in Finland.

Vocational studies are carried out in specialised vocational schools and can take three to four years, leading to specialist vocational qualifications. Vocational education and training is popular in Finland; more than 40% of the relevant age group starts vocational upper secondary studies immediately after basic education. The biggest fields are technology, communications and transport and social services, health and sports.

The Finnish National Board of Education decides on the national qualification requirement for each vocational qualification, determining the composition of studies and objectives, core contents and assessment criteria for study modules. It also includes provisions on student assessment, student counselling, on-the-job learning, special education and training, educational arrangements for immigrants and apprenticeship training. The content of local curricula is defined in the national qualification requirement as well. These requirements are drawn up in co-operation with employers' organisations, trade unions, the Trade Union of Education and student unions. National Education and Training Committees, local tripartite bodies as well as other representatives of working life take part in the curriculum work as advisers and consultants.

Higher education is provided by universities and polytechnics (also known as universities of applied sciences). Universities emphasise scientific research and instruction, whereas polytechnics adopt a more practical approach. Higher education institutions are very autonomous in organising their instruction and academic year.

There is restricted entry to all fields of study. The applicant volumes outweigh the number of places available. Therefore universities and polytechnics use different kinds of student selection criteria. Most commonly these include success in matriculation examination and entrance tests.

TEACHER TRAINING

Teachers in Finland are highly trained. In general education all teachers are required to have a Master's degree. In vocational education teachers should have a Master's degree or Bachelor's degree. The high level of training is seen as necessary as teachers in Finland are very autonomous professionally.

Specifically, according to the *Teacher Education Development Programme* (2002),⁶ the teacher education programmes should help students to acquire, among other things, the following:

- High-level content/subject matter knowledge, pedagogical knowledge, pedagogical content knowledge, contextual knowledge and knowledge about nature of knowledge.
- Social skills, such as communication skills and skills to cooperate with other teachers and skills to use ICT.
- Moral knowledge and skills, such as the social and moral codes of the teaching profession.
- Knowledge about the school as an institute and its connections to the society.
- Skill to cooperate with other teachers and skills for the school–community (local contexts and stakeholders)–parents partnership.
- Academic skills, such as research skills.
- Skills needed in developing local curricula, the planning of teaching and organising the assessment of teaching and learning.
- Skills needed in developing one's own teaching and the teaching profession.

When these national-level aims are compared to the description of teacher professionalism,⁷ several similarities can be recognised. The versatile knowledge base – including subject matter knowledge, pedagogical knowledge, pedagogical content knowledge and contextual knowledge; competence for networking and operating in partnerships and, moreover, competence for life-long-learning – are an essential part of Finnish teachers' competence.

Primary teachers are educated in five-year master level programmes (300 cp.).⁸ The programme consists of studies in the major (140 cp) chosen out of education or educational psychology. The first minor is multi-disciplinary studies (60 cp.) – studies of the pedagogical content knowledge of school subjects at primary level. The students also choose another minor subject (60 cp.) and other optional studies, like communication and language studies (40 cp.).

Teacher training can be either concurrent, with pedagogical training integrated into the Master's programme, or consecutive, with the pedagogical training completed after the initial degree. The latter is the case for example in vocational teacher education. The consecutive model also serves those who decide on a teaching career later.

The Finnish National Board of Education (FNBE) is responsible for national-level implementation of educational programmes and strategies (eg ICT strategies) and for financing ICT tools and long-term in-service training programmes for teachers. For example, in year 2016 FNBE opened a call for projects emphasising the development of innovative learning environments in basic and upper secondary education and training of teachers in these environments.

At most levels of education, teachers are required to participate in in-service training every year. The state funds in-service training programmes, primarily in areas important for implementing education policy and reforms. Education providers can also apply for funding to improve the professional competence of their teaching personnel. The Osaava Programme (2010–16) is a national fixed-term programme for continuing professional development (CPD) aiming to ensure systematic CPD of staff in schools. The programme supports education providers to systematically and continually develop the skills and knowledge of their staff according to locally identified needs. Participants in Osaava and other government-funded CPD increased from 30,000 in 2009 to almost 70,000 in 2013.

Contrary to pre-service teacher education, the in-service education or professional development of teachers is the responsibility of the municipalities/cities in Finland. Therefore, municipalities have organised short in-service courses and professional development projects (PDPs) for teachers. Special centres for in-service training have been established in many municipalities to co-ordinate local development efforts and in-service training. Some projects have substantially benefited from local and national networking,^{9,10} and teachers' pedagogical associations also organise in-service training for teachers. For example, the Finnish Association of Teachers of Mathematics, Physics and Chemistry has annually organised in-service days for science teachers.

⁶ Teacher Education Development Programme. (2002). Helsinki: Ministry of Education, Department for Education and Research Policy.

⁷ Teacher professionalism is a complex concept, and it has been defined in several ways. In addition, several other terms, such as effective, competent, expert, quality, ideal or respective teacher, are used to describe a professional teacher (Cruickshank & Haefele, 2001; Stronge & Hindman, 2003). Teacher professionalism also refers only to the status of teachers. It depends on school level factors and cultural and education policy factors in addition to individual characteristics of a teacher, like teacher's knowledge base, teaching philosophy and interaction and collaboration skills (Müller, Norrie, Hernández, & Goodson, 2010).

⁸ One credit point (cp) equals approximately 27 work hours, including lectures, small-group work and self-directed learning.

⁹ Lavonen, J., Juuti, K., Aksela, M., & Meisalo, V. *A professional development project for improving the use of information and communication technologies in science teaching* (2006). *Technology, Pedagogy and Education*, 15(2), 159–174.

¹⁰ *Koulu Kaikkiäällä* [Omni School] is a network emphasising out-of-school learning and use of technology in this learning www.kaikkiäällä.fi / *Luma Suomi* ohjelma [STEM education network] is facilitating the teaching and learning of STEM subjects all over Finland www.luma.fi/suomi/ / *eNorssi-verkoston* [Network of teacher training schools] supports the use of technology in pre- and in-service training of teachers (www.enorssi.fi)

However, there are challenges in Finnish in-service education. According to the TALIS survey, teachers are not so eager to engage in-service education as some other countries.

In February 2016, the Ministry of Education established the Finnish Teacher Education Forum aiming to foster the renewal of teacher education as a part of national reform program. The aims of the Teacher Education Forum are to prepare a development program for teachers' pre- and in-service education (life-long professional development), to support the implementation of the program and to create the conditions for the renewal of Finnish teacher education through development projects. The program should describe what kind of teacher education and continuous professional development of teachers are necessary to ensure that teachers are able to support students in the classroom to learn the competencies (knowledge, skill and attitude) needed today, tomorrow and in future. The forum will support teacher education institutes to create environments and courses where student teachers have possibility to become familiar with new pedagogy, learning environments and digitalisation of teaching and learning.

SCIENCE EDUCATION IN FINLAND

Finland changes its National Core Curriculum (NCC) every ten years and in August 2016 a new curriculum comes into force in Finnish schools. Some key aims are to:

- A focus on generic competences and work across rather than within school subjects.
- Collaborative classroom practices and project work.
- An emphasis on the role of technology in teaching and learning.

Despite some interpretation that these reforms meant the end to subjects in the Finnish curriculum, the Head of Curriculum Development at the Finnish Board of education said: "Traditional school subjects will live on, though with less distinct borderlines and with more collaboration in practice between them".

As a starting point in 2012, the government proposed that for Basic Education a pupil's minimum amount of lessons would be 222 in grades 1–9. Content in all subjects has been reduced, but more lesson hours would be given to Social studies, Physical education and Music & visual arts. In grades 1–6, 'integrated environmental studies' would include: biology, geography, physics, chemistry and health studies.

There would also be seven dimensions of broad-based competence:

- Thinking and learning.
- Cultural competence, interaction and expression.
- Looking after oneself, managing daily activities, safety.
- Multi-literacy.
- ICT competence.
- Competence required for working life and entrepreneurship.
- Participation, empowerment and responsibility.

Collaborative classroom practices, where pupils may work with several teachers simultaneously during periods of phenomenon-based project studies, are to be more emphasised in the new curriculum. All schools have to design and provide at least one such study-period per school year for all students, focused on studying phenomena or topics that are of special interest for students. Students are expected to participate in the planning process of these studies. School subjects will provide their specific viewpoints, concepts and methods for the planning and implementation of these periods. On what topics and how these integrative study periods are realised, will be decided at local and school level.

The following table outlines the distribution of lesson hours in the current general upper secondary education for young people. The average scope of one course is 38 lessons. Consequently, in order to reach the number of lessons, the number of courses on the time allocation table should be multiplied by 38. The duration of a lesson must be at least 45 minutes. The number of compulsory courses varies between 47–51, depending on the choice between basic and advanced syllabus in mathematics. The entire syllabus in general upper secondary education for young people comprises 75 courses. In addition to the minimum courses defined by legislation, schools may offer school-specific specialisation courses and applied courses.

| Subject or subject group | Compulsory courses | Number of national courses offered as specialisation courses |
|--|--------------------|--|
| Mother tongue and literature | 6 | 3 |
| Languages | | |
| A-language, starting in grades 1–6 of compulsory education | 6 | 2 |
| B-language, starting in grades 7–9 of compulsory education | 5 | 2 |
| Other languages | | 16 |
| Mathematics | | |
| basic syllabus | 6 | 2 |
| advanced syllabus | 10 | 3 |
| Environmental and natural sciences | | |
| Biology | 2 | 3 |
| Geography | 2 | 2 |
| Physics | 1 | 7 |
| Chemistry | 1 | 4 |
| Religion or ethics | 3 | 2 |
| Philosophy | 1 | 3 |
| Psychology | 1 | 4 |
| History | 4 | 2 |
| Social studies | 2 | 2 |
| Arts and physical education | 5 | |
| Physical education | 2 | 3 |
| Music | 1–2 | 3 |
| Visual arts | 1–2 | 3 |
| Health education | 1 | 2 |
| Educational and vocational guidance | 1 | 1 |
| Compulsory courses | 47–51 | |
| Minimum total of specialisation courses | 10 | |
| Applied courses | | |
| Minimum total number of courses | 75 | |

Despite a downturn in mathematics, Finnish students remain one of the best performers among the OECD countries involved in PISA. Finland came in sixth place among the OECD countries in mathematics, third in literacy and second in science. Shanghai-China, Hong Kong-China, Singapore, Japan and Finland are the top five performers in science in PISA 2012. Pasi Sahlberg¹¹ has suggested that Finland's exceptionally good performance in science is due to:

- A redesign of Primary science teacher education over the past 20 years focused on increasing opportunities for experiential and hands-on science (and an increase in Primary teachers with science backgrounds).
- A redesign of the Primary science curriculum away from academic knowledge and towards hands-on experiments and problem solving.
- Coherence in the above two factors.

Finland remains the best in literacy and science among the European countries. Finland's proficiency in scientific literacy ranked in fifth place among all participating countries and economies. Finland's position was among the best in the OECD countries along with Japan, Estonia and Korea. Finland's average scientific literacy has dropped by 18 points relative to the 2006 survey, when the focus was on science.

The government has prioritised STEM over the past 20 years through a major investment in LUMA, a national project to improve skills in mathematics and natural sciences. LUMA Centre Finland was established 8 November 2013 as the umbrella organisation for LUMA Centres in Finnish Universities to strengthen and promote their collaboration on national and international level. The LUMA Centre Finland network is directed and coordinated from the University of Helsinki. The LUMA Centre at the University of Helsinki includes seven so-called resource centres: BioPoP (biology), Geopiste (geoscience), F2k (physics), Kemma (chemistry), Linkki (computer science), LumO (pedagogy) and Summamutikka (mathematics). Activities include:

- Science clubs, camps, events, webzines and other activities for children and youth.
- Pre-service and in-service training for teachers, and interactive online web portals including videos and other materials as well as science classes and laboratories that support teachers in their work.
- Research on the teaching of mathematics and natural sciences and on the effectiveness of LUMA's own activities, and the development of them based on the research results.
- Collaboration with decision-makers and media, and especially with other active partners in the field.

The operations on LUMA Centre are funded by University of Helsinki's Faculty of Science, cooperating institutions and companies, grant-giving foundations, and private donations.

More than 30% of tertiary graduates in Finland are in science-related fields.

¹¹ Pasi Sahlberg, *Finnish Lessons. What can the world learn from educational change in Finland?* (2015). Teachers College Press.

APPENDIX 3:
COUNTRY REPORT:
GERMANY



GATSBY

I EVIDENCE GATHERING

This report has been written by Ginny Page and John Holman and is based on the following sources. Further details of the sources are in Annex 1.

- A. Desk research.
- B. Visits to three secondary Gymnasium schools: Klaus-Groth-Schule, Neumünster, 2 May 2016; Kieler Gelehrtenschule, Kiel, 3 May 2016; Kosterschule, Hamburg, 4 May 2016.
- C. Dinner discussions with teachers Dr Andreas Ellendt and Sven Rausch on 2 May 2016, and with teachers Tobias Schlegelmilch and Meike Ludzay on 3 May 2016.
- D. A meeting with researchers Dr Kerstin Kremer and Dr Sascha Bernholt, Leibniz-Institute for Science and Mathematics Education (IPN), Kiel, 2 May 2016.
- E. A visit to Kieler Forschungswerkstatt (KiFo) at the University of Kiel and meeting with Dr Katrin Knickmeyer and PhD students, 2 May 2016.

The visits were organised by Professor Knut Neumann, Head of the Department of Physics Education at the Leibniz Institute for Science and Mathematics Education (IPN) at the University of Kiel. All visits and dinners were accompanied by Professor Neumann and Professor Jeffrey Nordine, Associate Professor in the Department of Physics Education, Leibniz Institute for Science and Mathematics Education.

2 OUTLINE OF EDUCATION IN GERMANY

This is a summary: there is further detail in Annex 2.

Germany is the most populous country in the European Union, and 20% of its nearly 82 million inhabitants have a migrant background. However, unemployment rates are among the lowest across OECD countries, despite it being very difficult to get a job in Germany without having either completed an apprenticeship or achieved a higher qualification. Germany has high upper secondary education (i.e. 18/19 year olds) participation and attainment rates, largely because of a successful system, which combines academic and vocational programmes and institutions, many of which include work-based education.

Germany is a federation consisting of 16 states (Länder), each of which has a Ministry with considerable influence over education in that state, but particularly in terms of school entry, budgets, evaluation, and staffing. This means that education systems within Germany can vary quite considerably between Länder, though there are consistencies imposed by federal government in terms of teacher salaries and National Education Standards in curricula and assessment.

Primary education generally starts in the year in which a child is six, and lasts for four years, after which the pupil receives a final evaluative report. This is used by parents, together with discussion with teachers if necessary, to decide which sort of secondary school their children should attend. Generally young people will go to a nearby school. The critical choice between the more academic Gymnasium and the more vocational Gemeinschaftschule is made consensually by parents and teachers: there is no selection test at the end of primary school.

Secondary education in Germany has traditionally involved a 'tracking' system where young people attend one of 3–4 different types of school on the basis of their likely destination after compulsory schooling. These destinations include: lower level vocational training leading to skilled jobs; higher level vocational training at a technical university; or academic training leading to an academic university.

However, the 'PISA shock' of 2001 revealed that this tracking system may have contributed to attainment gaps between young people on the basis of socio-economic and cultural background, and could not be justified on the grounds of differences in academic aptitude. Most Länder are now moving towards a two-track system where at age 10–12 students enter a community school (Gemeinschaftschule) or comprehensive (Gymnasium), the former giving students another year of education before taking their leaving exams.

Another consequence of the results of international comparative studies is that national curricula have been thoroughly revised over the last decade. National Education Standards have been published and the Institute for Education Quality Improvement (IQB) at Humboldt University has implemented a regular, national programme of sample-based assessment, and assembled a pool of questions for use in the final leaving examinations in Gymnasias (the Abitur exams).

Despite this, decision-making on the detail of school curricula, the introduction of additional courses, organisation of instruction including grouping of pupils, choice of text books, and assessment of pupils' regular work, lies mainly with the schools.

School accountability in Germany is relatively light-touch. An external evaluation may be carried out every 3–6 years, but (depending on the state) this may be undertaken by a 'critical friend' from another school or by an external evaluator appointed by the Ministry. Either way, the purpose is developmental rather than judgemental – the results are not published and there are no league tables.

Germany's teachers have the longest pre-service teacher training among all PISA 2012 countries comprising two phases: Masters level courses in a curriculum subject, pedagogy and educational theory; followed by 18–24 months of preparatory service in school. Teacher education programmes must be accredited, and follow common standards set by central government as well as regulations set by local Länder. Trainee teachers must pass a state exam before they become qualified.

Most teachers are employed by the state as higher level public servants or Beamte. Beamte have permanent tenure, generous salaries usually aligned to a national scheme, and receive pensions of around 70% of their final salary. With these advantages and high status also come high expectations of German teachers' professional commitment, particularly in the additional hours they work.

3 SCIENCE EDUCATION IN GERMANY

3.1 SCIENCE IN THE GYMNASIUM SCHOOL CURRICULUM

Traditionally the sciences are taught separately, i.e. there are lessons in physics, in chemistry and in biology. Within a Land, the total number of hours within each grade are fixed, while hours dedicated to separate subjects can vary. A lesson period is typically 45 minutes long but many schools teach in double periods i.e. 90 minute lessons.

Grades 11–13 are voluntary but, depending on the type of school, need to be completed in order to gain the Abitur and get access to university, and will include a range of up to 10 different subjects/courses. This breadth of choice means that post-16 physics and chemistry classes may be very mixed in terms of student ability and motivation in the subject. During upper secondary education students are able to choose which higher classes they would like to focus on, known as their 'profile'. Students who choose a science profile must have a 'profile-defining subject' (such as physics) and will choose additional subjects complementary to the main subject. Profile subjects will be given more lesson time than other non-core subjects.

In 2005 National Education Standards (NES) for grade 10 (16 year olds) in biology, chemistry and physics were published. The standards define expectations on student competence in the following areas: content knowledge, scientific inquiry (including experimentation skills); communication (including research and presentation skills); and 'assessment' (including social and ethical implications of science and technology). Following this, national assessments in the sciences are now administered to a sample of grade 9 students across the Länder every three years.

3.2 SCIENCE TEACHERS

Science teachers in Germany are highly qualified. Their training has two phases – five years in university achieving Masters level in typically two science subjects, pedagogy, and educational theory, followed by 18–24 months in-service preparation in school. In order to qualify as a science teacher at the end of these seven years, trainees must demonstrate their competence by teaching an exam lesson in each of their subjects, taking an oral exam, and submitting a thesis.

There is little evidence of any major problems in the supply of science teachers in Germany (although exceptions to the rules regarding teacher training can be made for physics teachers who are always in demand). It is likely that the advantages afforded by being Beamte – both in terms of status and tangible benefits – ensure that teacher retention rates are high. As teachers working in private schools are not Beamte, this tends to be a less attractive option than working in a state school.

3.3 SCIENCE BEYOND THE SCHOOL CURRICULUM

Germany has a large and very successful manufacturing sector (24% of GDP compared to the UK's 12%). This has remained relatively buoyant despite the Euro crisis and demands that people are qualified in STEM at graduate and technical levels. There appear to be many initiatives to introduce and engage pupils in STEM industries, often running in close collaboration between an individual employer and the local schools. At the federal level too, large multinational companies like Siemens, Volkswagen and Deutsche Telekom have extensive school outreach programmes.

Many of these initiatives, at local and at national level, aim to attract more girls into STEM, especially engineering, and to broaden the range of occupations that girls consider. These include: National Girls' Day whereby businesses, research centres and other institutions put on simultaneous open day events for girls, mainly aged 14–15; and 'Go-MINT', a national pact among businesses and organisations in MINT (Mathematics, Information technology, Natural sciences, Technology) aimed at increasing young women's interest in scientific and technical degree courses and attracting female university graduates to careers such as engineering.

4 RELEVANT FINDINGS

4.1 TYPES OF PRACTICAL SCIENCE

In the schools we visited, practical work was highly integrated with theory teaching, used both to demonstrate new concepts and to strengthen understanding of concepts already introduced. While lesson periods were generally 45 minutes long, the majority of science lessons were double periods (though these may be either side of a lunch break). However, the compromise of this set-up would be that teachers saw their students less frequently.

Class sizes varied between 14 and 27 (though we were told sizes typically varied between 22 and 27), but within classes, most practical work was undertaken by groups of students working collaboratively through an exercise set by the teacher. Groups comprised around 4 students on average, though this did rise to 8 in one school. In some instances group size was dependent on availability of equipment: Kieler Gelehrtenschule purchased boxed sets of physics equipment at €350 designed to enable groups of older students to independently explore concepts in acoustics and optics.

Teachers had a great deal of freedom to choose and develop the practicals most appropriate for their lessons. There did not appear to be many standardised experiments externally prescribed. In Klaus-Groth-Schule, teachers adapted experiments they had themselves experienced as undergraduates, 'piloted' them with their students, then refined protocols and acquired new equipment in order to improve on the experiment in future years.

Schools did moderate amounts of fieldwork according to their curriculum, but found it difficult to go further than their school grounds, as the additional time taken out of the school day caused problems for other teachers. Residential fieldwork was uncommon. However, the Kieler Forschungswerkstat (KiFo) school science laboratory in Kiel can facilitate field trips to the nearby Baltic Sea, as well as offer marine- and energy-themed practical workshops to school groups visiting the facility, and send boxes of fieldwork kits out to schools.

In Klosterschule, students undertook some sort of fieldwork once or twice each year, as it was generally included in the themed projects they were all expected to undertake. Themes included 'wood' and 'water' and were designed to uphold the school's emphasis on the arts and creativity. This was also exemplified in the Pinhole Camera workshop we witnessed – delivered by a visiting artist with support from the physics teachers and designed to involve older students in a thoroughly interdisciplinary project over 2.5 days.

4.2 HOW FREQUENTLY?

Teachers found it hard to estimate how much practical work they undertook, though one physics/maths teacher suggested it occupied about 25% of his teaching time, and another who had designed a project-based course suggested that around two thirds of his teaching was practical. Laboratories were occupied most of the time, and it appeared that when science teachers had a 90-minute lesson they would aim to include practical work within it. However, the fact that teachers had to do all the preparation beforehand and clearing up afterwards was a clear limitation on the frequency of experimental work.

Teachers also told us they tended to do less practical work as students got older. This was due to the nature of the concepts changing (from phenomenological to more theoretical) and their complexity increasing (making teachers feel that the associated practical work would also be complex and therefore expensive). One school felt they did less practical work in biology because the concepts involved were less conducive to practical work, but this was not consistent across all the schools we visited.

4.3 ATTITUDES TO PRACTICAL SCIENCE

We found all the teachers we spoke to were very thoughtful about the purposes of practical science, and confident about its use in their teaching. They had different reasons for the practical work they undertook, from student motivation, to preparation for equipment they would encounter at university, to developing skills such as teamwork and communication. Some of these differences were down to differences in subjects – we heard that biology teachers may use practicals more as part of inductive processes than deductive, and at Kieler Gelehrtenschule, practical work is used with younger students to develop positive attitudes towards nature by engrossing them in close and prolonged observation of various living organisms. A biology teacher told us that good practicals should be: purposeful, clearly demonstrative, universally engaging, and timed to include an introduction and discussion afterwards.

However, a common thread throughout our discussions was the use of practical work to give students an authentic experience of the complexity of scientific working, and in developing skills and behaviours associated with resilience, tenacity and ingenuity. It was clear to see that many students relished the opportunity to tackle science in this way, but not all groups we saw were equally engaged. Without a leader among them, some students were easily distracted and drifted off-task. It was likely that, among the older groups, these were students who had not chosen a science profile.

Students told us that practical work made science 'memorable' for them, and we detected very little anxieties about experiments not working, or whether the practical would be assessed: "We trust the teacher," said one student at Kieler Gelehrtenschule.

4.4 FACILITIES AND FUNDING

There was no question for the teachers in the schools we visited: practical work was fundamental to science. For their Principals, science was a subject important to the status of the school and, for Kieler Gelehrtenschule in particular, merited a significant investment in laboratories and equipment, with one exemplary chemistry laboratory incorporating six fixed fume cupboards. Teachers chose to augment the school experience by taking grade 9 students to the DESY (Deutsches Elektronen-Synchrotron) lab in Hamburg every year, and older students to Kiel University to undertake genetics experiments. Generally we saw that the facilities for biology were less sophisticated (and therefore less expensive) than those for physics or chemistry.

In all school laboratories, whether the services were fixed around the room or only at the side, the seating was as flexible as possible so that teachers could design the room to fit their lesson plans.

The equipment was generally of high quality but, apart from microscopes, there were rarely sufficient numbers for individual or paired practical work. This was in part due to teacher preference for group activities, but funding was also a limiting factor (as was the lack of technical skill on staff to fix broken equipment). The schools we visited seemed well funded, but science departments had relatively little control over their own budgets, making everyday purchasing as well as forward planning difficult.

Text books were available but relatively little use was made of them. However, teachers routinely gave students worksheets, which guided the conduct and the recording of their practical work.

4.5 TECHNICAL SUPPORT

None of the schools we visited employed technicians to support practical science and we were told this was common across all Länder. Instead the teacher has all the responsibility for preparing before, and clearing after, practicals, as well as acquiring, storing and maintaining all consumables and equipment. This was a source of frustration for the teachers we spoke to as it limited their teaching time (compared to teachers in other subjects) – two chemistry teachers in different schools estimated they spent as much time preparing for practicals as they did teaching them, and one spent considerable time in his holiday stocktaking and clearing up.

The lack of technical support was also a factor in schools making the decision not to undertake practicals with health and safety implications. Students at Klaus-Groth-Schule are taken to the nearby university to undertake microbiology experiments as the teacher felt the school environment was inappropriate to working with bacteria. More generally attitudes to health and safety in laboratories were proportionate to the activity and the behaviour of the student group.

4.6 PROJECT WORK

We saw plenty of examples of project work in the schools we visited, though this tended to be in physics and technology rather than chemistry or biology, and almost always involved pairs or groups. The teachers we spoke to were interested in the possibility of more students undertaking independent research projects, but they were generally limited by their time and the availability of specialist facilities.

Only one of the schools we visited had embedded project work as a standard part of their curriculum. At Klosterschule students generally do two projects a year on given themes, and can also choose courses which are entirely project-based. One such course – Naturwissenschaften or NaWi, meaning natural science – was designed to offer grade 9–10 students opportunities to conduct a piece of their own project, generally focused on creating a product through a process of research, design, testing, improving and presenting. Students could choose any topic they liked, work on their own or in groups, and undertake a series of short projects or work on the same project over the two years of the course. But a fundamental part of any project had to be the planning and conduct of a scientific experiment that would enhance what the student was building.

At the other schools teachers chose to do projects with certain groups as part of a general belief in the benefits of giving students the chance to go through the process of applying and refining their knowledge. In Kieler Gelehrtenschule, grade 9 chemistry students had the freedom to design an experiment that would explore any aspect of the element carbon. Some students chose to analyse the calcium carbonate content of different water samples, others the effect of climate change on marine plankton. There were no set procedures, and both teacher and students accepted that the experiments might go wrong, or fail to yield interesting results. In Klaus-Groth-Schule, a large, bright room had been converted into a multi-purpose activity area where students could work on their own as part of design and build competitions, revise for exams, or use some of the kit available for their own interest. With comfortable beanbags and computers, this was very much a space for freedom and creativity for the students outside curriculum lessons.

In fact, this process of finding success through failure was considered to be an important learning objective by many of the science teachers we spoke to. The teachers rarely intervened, allowing students themselves to discover which experiments weren't viable, and when improvements were needed. As a physics/math teacher said: "The way to understanding is long and winding". In the schools we visited, science teachers felt it important to give students the opportunity to make that journey as independently from them as possible.

4.7 ASSESSMENT OF PRACTICAL SCIENCE

Practical work was largely seen as a way of developing knowledge and understanding through its application. Practical skills were thus developed – and we certainly saw all ages of students use kit such as Bunsen burners, glassware, circuits and living organisms with competence and confidence – but these were not generally assessed. Only in Klaus-Groth-Schule were we told that chemistry students were tested on their practical skills as part of the Abitur exam. This was possible as the state of Schleswig-Holstein allows teachers to construct the Abitur in natural sciences, so in this case teachers could design a test they knew was implementable on the same day as the 5-hour written exam. Students were given a box of chemicals and a task, and an hour to complete it. This test, as with the written exam, was submitted to the Ministry for approval beforehand. Generally the teacher will propose four tasks from which the Ministry chooses two that can be used, and care is taken to ensure tasks vary each year. In Hamburg (which is a different state), we were told such a system would not be possible.

Despite a great deal of formative use, teacher assessment of practical work still forms an important, summative part of the final grade in the Abitur. Around 40 courses are taken during the last two years of upper secondary education, and teachers can award a maximum of 15 points for each course. Teachers often awarded marks for what they variously called ‘participation’ or ‘engagement’. A student would be given good marks if they contributed well in groups, concentrated on the task at hand, and showed through their questions and actions that they were thinking deeply about the ideas behind the activity. A teacher of a project-based course told us that they used to ask students to write up a report but he found it wasted their time, and the skills used were not those he was interested in. Instead he used his own observations and discussions to assess their scientific thinking and commitment to the project.

Despite the importance of the Abitur grade in gaining university entrance, older students did not seem unduly concerned about how what they were learning, or how they were assessed, was going to optimise their final results. One group of grade 12 chemists told us that because their marks were spread across so many courses, they could afford to do badly in some because they could make up the marks elsewhere.

Neither did teachers feel constrained by assessment, and there was a strong feeling that the purpose of their teaching was not to train students to pass exams – if the student chose to work hard they would succeed, if they didn’t then they would not do well.

4.8 TEACHERS’ TRAINING AND CPD

Researchers at the Leibniz Institute for Science and Mathematics Education (IPN) at the University of Kiel told us that science teachers in Germany do practical work because of their own backgrounds in science, as well as inherent belief that science is practical.

Undoubtedly, teacher training that involves studying to Masters level in two sciences, as well as pedagogy and educational theory, equips German Gymnasium teachers with a very solid theoretical foundation on which to draw in their teaching. Teacher education courses at university will also typically include laboratory classes and seminars covering skills in planning and performing experiments, as well as handling school-level equipment. We certainly observed a high degree of practical confidence and competence, with teachers devising new practicals and building sophisticated equipment (such as a cloud chamber and a supercomputer).

The teachers and educationalists we spoke to held deep and secure ideas about the purposes and practices of education. We heard about the concept of ‘Bildung’ - considered by many as fundamental to teaching and education in Germany. Rooted in 18th century philosophy, Bildung sets out an ideal whereby the student is responsible for their own development, and their schools are responsible for guiding their formation as well-rounded individuals in terms of knowledge, skills and attitudes. Similarly, we were aware of the concept of Beruf, which we might translate as rather more integrated attitudes to the vocational in education. Whether these concepts are implicit in teachers’ own experiences of education, or made explicit during their professional training, it is tempting to speculate on their particular impact on science education in terms of the role of practical and project work.

The two-year preparatory service science teacher trainees undertake also offers significant opportunities for development of pedagogy prior to attaining qualified teacher status. The KiFo science outreach laboratory in Kiel gave additional opportunities to student teachers as well as science education PhD students to develop their practice and ideas as part of the lab's outreach work, enabling them to offer visits and workshops to over 100 school groups each year.

The teachers we spoke to had strong beliefs about the purposes of science education, were held in a great deal of respect in the classrooms we visited, and were generally deferred to by the Principal in most decision-making. While it is impossible to identify a single cause for the status of science teachers, it is likely that their high levels of training, the position of Beamte, and the more distributed model of leadership all contribute.

This was particularly evident in Klosterschule, where science teachers meet twice a year for major planning meetings, and also spend day a year planning with others in their subject. Teams of teachers for each grade also meet once a week. It was acknowledged that this took time away from teaching, and required the support of parents in terms of sending the students home during these days, but it also resulted in confident teachers and a coherent, relevant and constantly improving curriculum. These days were not considered 'training' days – they were how the school was run and an integral part of a science teacher's professional duties.

5 EMERGING LESSONS FOR ENGLAND

Science teachers in German Gymnasia are trained to Masters level in at least two science/maths subjects as well as pedagogy, and must demonstrate a required standard of knowledge and competence before being given their first teaching job. This is in contrast with requirements in England, where concerns over teacher recruitment may hamper raising the bar in teaching training. However, the typical placement of science educationalists in science rather than education departments has created closer links between these departments during teacher training and research programmes, and represents an example Initial Teacher Educators in England could replicate.

The example set by the Kieler Forschungswerkstat (KiFo) in deploying under- and postgraduates in the delivery of high-quality outreach, could work very well in science centres in England, particularly where they are in close proximity to teacher training institutions.

The practical work we saw was closely integrated with theory teaching, and generally involved purposeful applications of knowledge through which greater understanding could be acquired. However, it was clearly hard to do this adequately in single 45-minute lessons, so doing practical work meant seeing their students for longer periods but less often. This may be leading to German schools doing practical less frequently than in England, but arguably with more purpose.

Teachers in Germany feel strongly about the multiple benefits of practical, project-based learning in science, and have the freedom (in terms of both curriculum and assessment) to create courses which give students the opportunity to engage in long-term, interdisciplinary projects and to embed scientific thinking in traditional 'design and build' as well as art-based activities. Most students clearly enjoyed being able to be creative and make their own discoveries, though some used it as an excuse not to engage in the learning process. This approach, which gives students a lot of responsibility for their own success, may be less acceptable in schools in England.

There was a strong culture of openness and trust in the schools we visited. The high standards of teacher training and the position of Beamte clearly confers a certain status on teachers. This is acknowledged in the professional autonomy individual science teachers are given in deciding what they teach, how they teach it, and how they assess it. While the views of parents are taken seriously by senior managers, we did not detect any undue external influence on science teachers' judgement. This enabled innovation in the science lab, and a culture of consensual (if perhaps time-intensive) decision making across science teaching teams. While accountability in the English education system remains a driving force in determining school behaviour, both Academies and Local Authority maintained schools might benefit from reflecting on their management systems, reducing hierarchies, and prioritising time within the working week for science staff to meet, discuss and agree on their practice.

The absence of science technicians in German schools causes significant reductions in teaching time, and results in expensive equipment being wasted as teachers have not the time nor skill to fix it when it breaks. Schools in England considering reducing their technician hours should calculate the full economic cost of doing so before taking such action.

Teacher demonstrations were used to good effect in terms of student engagement, particularly at Klaus-Groth-Schule, where the 'Experiment of the Month' attracts a large number of keen students during their lunchtime. This sort of activity is something we envisage technicians, STEM Ambassadors and trainee teachers might easily do more of in schools in England.

All the schools we visited had at least two designated laboratories per subject, which were well used with few 'empty' periods. Each had a spacious preparatory room and were generally built to high specifications with flexible furniture conducive to group work. We heard that teachers were closely involved in any rebuilding or refurbishing of their laboratories.

Budgets for science were modest, and money was often cited as a limiting factor. However schools were able to apply to alumni organisations, which were proving to be more flexible than the local Ministry in terms of funding a particular piece of equipment, or a higher standard of refurbishment. It would be useful to identify how prevalent such organisations are in the UK, and explore whether more could be done to strengthen their role in supporting practical science.

For more than a decade, Germany has worked successfully on reducing the social inequalities revealed by the PISA programme. The PISA 2012 results showed that England had a relatively large difference in the performance of lowest and highest achievers, greater than the OECD average. The publication of PISA 2015 results, with their emphasis on science, could prove a spur to UK governments making more progress in this area as part of the next wave of reforms in curriculum and assessment.

ANNEX I: SOURCES OF EVIDENCE

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A. HALF DAY VISITS TO SECONDARY SCHOOLS ON 2 MAY, 3 MAY AND 4 MAY 2016.

Klaus-Groth-Schule, Parkstraße 1, 24534 Neumünster, Germany

The school was created in 1888 and has been in its current building since 1911. There are now 850 students and 68 teachers on staff. The school is a 'classic Gymnasium' i.e. state funded with a focus on academic education, though 50% of its grade 5 intake have a migrant background. The school has a focus on languages and natural sciences, and has been awarded a certificate in MINT, which recognises excellence in STEM education and enables the school to be part of a national network of schools, employers and research institutions. The school day runs from 7.45am to 16.05pm, and has a close association with the University of Kiel, enabling students to interact with academics at some point every year.

We observed and spoke to students in a grade 5 chemistry class, a grade 9 physics class, and a grade 8 ANT (applied science) class. We also met with a maths/chemistry teacher, a biology/chemistry teacher and a physics/ANT teacher during a roundtable discussion. We were also shown around the school by the Principal.

School contact: Principal Mr Jörg Jesper

Kieler Gelehrtenschule, Feldstraße 19, 24105 Kiel, Germany

Established in 1320, Kieler Gelehrtenschule is one of 10 state-funded Gymnasium in the locality and distinguishes itself by teaching Latin, and offering very modern environments in which to learn the sciences. Around 50% of its 500 pupils go on to university.

We observed and spoke to students in a grade 7 chemistry class, grade 9 chemistry class, grade 11 physics class and a grade 7 biology class. We were accompanied for most of the day by a chemistry/physics teacher, and also met with a biology/english teacher and a maths/physics teacher, both in their classes and over lunch. We also spoke with the Assistant Principal during a roundtable discussion.

School contact: Assistant Principal Steffen Jeschke

Klosterschule, Hamburg, 4 May 2016

The school was founded in 1872 as a secondary school for girls. Today the school is a state-funded Gymnasium attended by 950 students who originate from 64 different countries. The school specialises in the arts, but 40% of older students choose a science profile and the curriculum has been designed to be interdisciplinary and project-based in order to maximise creativity in the school. The school received additional funding from the state in order to develop their arts specialism, though this had to be matched from other sources. The school operates a policy of 'open doors', welcoming visitors to observe their practice, and students from other countries to undertake exchange trips. It also has an inclusive ethos, which extends to offering a special curriculum for recent 14–15 year olds migrants centred on German, English and maths.

We observed and spoke to students in a grade 11 art and physics 'pinhole camera' workshop, a grade 9 chemistry class, a grade 9 NAWI class and a grade 11 chemistry class. We were accompanied for most of the day by a maths/physics teacher, and also met with a physics/biology/NAWI teacher and the pinhole workshop specialist. We also met with the Principal, a biology/chemistry teacher, during a lunch meeting.

School contact: Teacher Tobias Schlegelmilch

ANNEX 2: EDUCATION IN GERMANY – A BRIEFING NOTE

ABOUT GERMANY

Germany is a federal republic, with a population nearing 82 million, making it the most populous country in the European Union. Around 20% of the German population have a migrant background and 8 million are foreign residents. Germany performs well in many measures of well-being relative to most other countries in the OECD Better Life Index: above average in education and skills, work-life balance, jobs and earnings, environmental quality, social connections, housing, personal security and subjective well-being, but below average in civic engagement. While the average household net-adjusted disposable income per capita is more than the OECD average, there is a considerable gap between the richest and poorest – the top 20% of the population earn more than four times as much as the bottom 20%.

Germany's unemployment rates are among the lowest across OECD countries (5.7% of 25-64 year-olds in 2011, compared to the OECD average of 7.1%), and Germany is the only OECD country where unemployment rates fell between 2008 and 2011 (in March 2013, unemployment was 5.4%, compared to the OECD average of 7.9%). Young people are well integrated in the labour market, and only 11% of 15–29 year-olds were not in education and not employed in 2011 (compared to the OECD average of 15.8%).

THE GERMAN EDUCATION SYSTEM

Germany is a federation consisting of 16 provinces (Länder). Responsibility for the education system is divided between the Federation and the Länder. There can be wide variations between Länder, but each Land has a Ministry which exerts significant influence on education in that region, including budgets, teacher employment, school-leaving exams, and school evaluation. Decision-making for the organisation of instruction, including grouping of pupils, choice of text books and assessment of pupils' regular work, lies mainly with the schools.

As a rule, general compulsory schooling begins for all children in the year in which they reach the age of six and involves nine years of full-time schooling. The Grundschule (primary school) is attended by all school-age children and generally covers grades 1 to 4. There is no leaving examination at the end of primary school, and, as a rule, pupils are not awarded a leaving certificate, but do receive an evaluative report for their final year. The decision as to which kind of secondary school to transfer to at age 11 belongs mainly to parents with advice from teachers, though students generally attend their local school: there are no entry tests. But there is increasing demand from parents to send their children to the most prestigious schools, driving competition between schools with good reputations.

The right of parents to choose a school for their children does not mean that a pupil has the right to be accepted by a specific school. Many schools must take local students as a priority, while some can select on the basis of a specific interest or aptitude. However, parents may be able to choose a school other than that which is responsible for the local area and apply to the school authority to admit their child to that school. The school authority then decides on the merits of each particular case, following consultations with the parents and the authority maintaining the school.

Until relatively recently, secondary school students in Germany were 'tracked' into three different school types which would progress them into apprenticeships, higher vocational education or academic study at university. In the (late) 1960s, secondary comprehensive schools (Gesamtschulen) combining all three tracks into one school were introduced, and the system is designed to include bridges between tracks. But recent analysis using data from international performance measures has shown that there is relatively little difference in student achievement between the three tracks and strong correlation between students' achievement and socio-economic status.¹ Today, a considerable number of the Länder are implementing a two-track system giving students (and parents) the choice between a Gemeinschaftschule (or Stadteilschule or Regionalschule) for the more vocational, or the Gymnasium for the more academic. Whether in the two-, or three-track system, each type of secondary school has a different duration, different school-leaving exam, and different regulations for teachers and school evaluations.

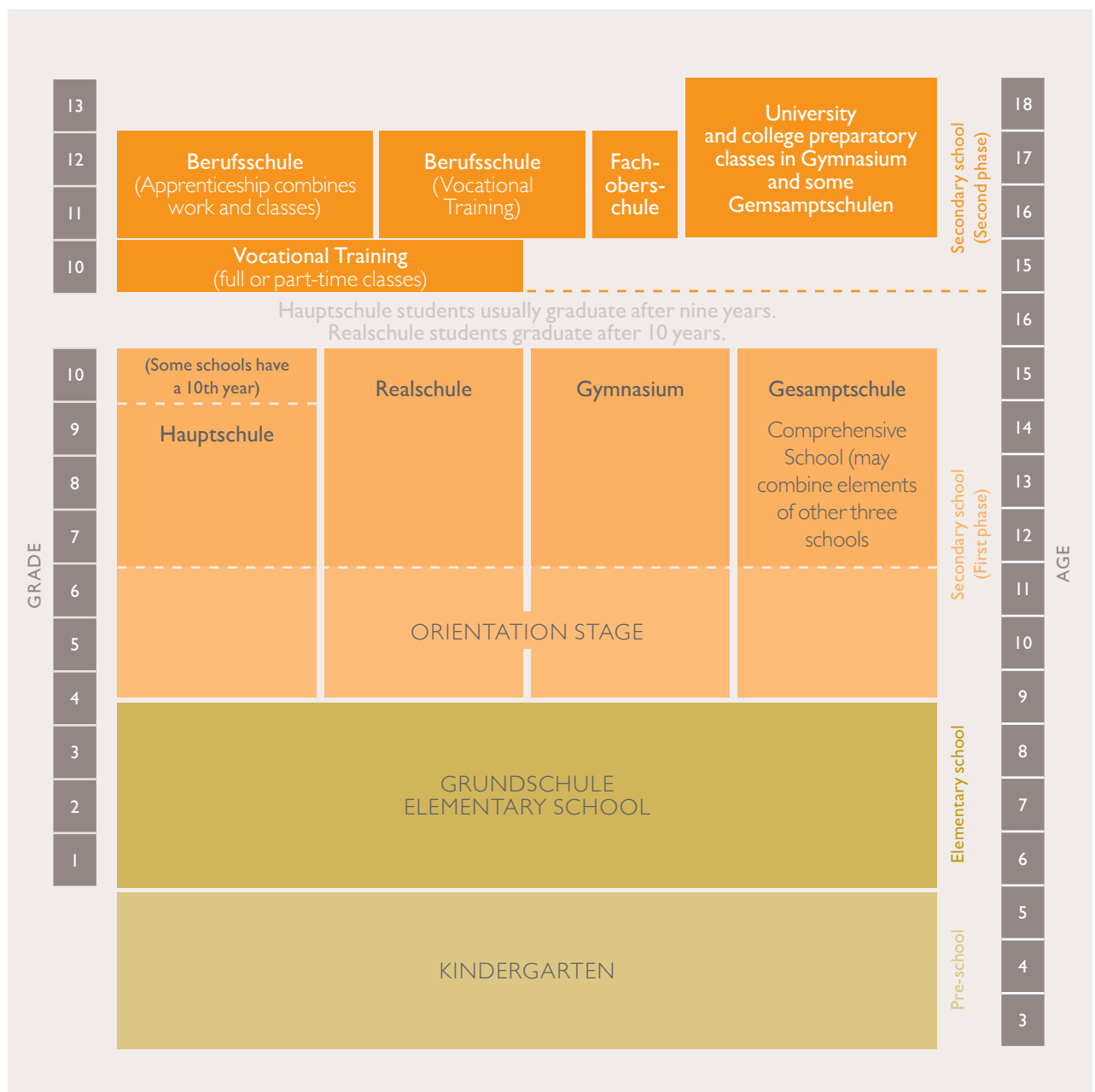
¹ Neumann, K., Fischer, H. E., & Kauertz, A. *From PISA to educational standards: The impact of large-scale assessments on science education in Germany* (2010). *International Journal of Science and Mathematics Education*, 8(3), 545-563.

Lower secondary level comprises grades 5–7 to 9–10 of school and is predominantly of a general nature aimed at preparing students for courses at upper secondary level (grades 10–11 – 12–13). Germany has high upper secondary education attainment rates (87% of 25-34 year-olds, compared to the OECD average of 82% in 2011). Half of those enrolled (49%) were in vocational programmes, with the majority (43%) in the dual system combining school-based and work-based education (compared to OECD average of 12%).

Upper secondary education may involve a change of institution, particular if following a vocational track where the Berufsschule combines part-time academic study and apprenticeship. The successful completion of an apprenticeship programme leads to certification in a particular trade or field of work. These schools differ from the other ones mentioned in that control rests not with the local and regional school authorities, but with the federal government, industry and the trade unions.

The university system comprises general universities and 'universities of applied sciences', and for those entering occupational work there are opportunities for continuing education and training through 'trade and technical schools' and 'adult education colleges'. In order to enter a general university, students are generally required to have passed the Abitur – the school leaving exam administered in grade 13 of the Gymnasium.

The system operates within a tightly regulated framework, with regulations for the vocational schools laid down by the Land and employers following a federal framework. It is very difficult to get a job in Germany without having either completed an apprenticeship or achieved a higher qualification.



CURRICULUM AND ASSESSMENT

The agreement reached in December 1993 (amended in September 2014) by the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder (Kultusministerkonferenz – KMK) concerning the types of schools and courses of education in lower secondary level, lays down a framework schedule for grades 5–9/10, requiring certain core subjects in every type of school and course of education: German, mathematics, the first foreign language, natural and social sciences. Music, art and sport, at the very least, have to be among the other compulsory or elective subjects offered. A second foreign language is mandatory at Gymnasium in grades 7–10.

An introduction to the professional and working world is a compulsory component of every course of education and is provided either in a special subject such as *Arbeitslehre* (pre-vocational studies, also called Economics-Work-Technology or Work-Economics-Technology) or as part of the material covered in other subjects or subject groups.

As a consequence of the results of international comparative studies, the curricula have been thoroughly revised over the past years. In most Länder the revision focused on the following main areas:

- Acquisition of basic competences in German and mathematics, and orientation towards professional practice and promotion of social competence, in vocational schools
- Definition of compulsory key areas of learning, measures to activate pupils and inspire problem-solving thought processes.
- Development of educational standards, binding for all Länder, which lay down expectations for the capabilities, skills and knowledge students will have gained in different subject groups at certain stages in their education.

As a rule, in any school, students will be taught a very mixed range of subjects throughout their secondary education, some being compulsory and some elective. These subjects include German, a foreign language (usually English), mathematics, physics/chemistry, biology, geography, history, social studies, music, art, sport, religious education and, in some Länder, domestic science and other work-related subjects. Students are rarely grouped according to ability.

The main subjects taught in the standard Gymnasium are: German, at least two foreign languages, mathematics, physics, chemistry, biology, geography, history, politics, music, art, sport and religious education. Grades 10–11 and 12–13 are voluntary, but need to be completed to gain access to university. During this period, students earn their Abitur and are able to choose which higher classes they would like to focus on, known as their 'profile'. Students who choose a science profile must have a 'profile-defining subject' (such as physics) and another science subject as their 'minor'.

The Abitur reflects student performance by way of: teacher assessment of c. 40 courses taken throughout the last two years of upper secondary education, which can comprise up to two thirds of the final grade; and results from a series of five exams (three written and two oral) taken in core subjects at the end of grade 13. Additionally, in some Länder, teachers also construct the Abitur exam, though they have to get it approved by the state before it is administered. It is accepted that the exam will only assess a proportion of content from any one course.

During the final Abitur examinations, students sit exams in five subjects, three are written exams and two are oral. Procedures vary by state, but written exams can last 4–5 hours and the subjects generally include: German, maths, and the profile-defining subject. In some Länder, students can choose to take an additional exam – written or oral – which may help to compensate for poor performance in another subject. Papers are marked by at least two teachers at the school. In some parts of Germany, students may prepare a presentation, research paper or participate in a competition, and make take oral exams if the written exam is poor.

Traditionally the sciences are taught separately, i.e. there are lessons in physics, in chemistry and in biology. A period is 45 minutes long but many schools teach in double periods i.e. 90-minute lessons. The balance of time allocated different subjects changes during the course of secondary education but, by grade 11, the chosen profile subject will have more time for in depth teaching than other subjects.

Teaching in schools in Germany is governed by regulations of various kinds laid down by the Länder. The prescribed curricula can include guidelines on the treatment of the various topics of instruction, distribution of materials and various teaching approaches. However, these guidelines are relatively slim and teachers have plenty of opportunity to tailor the school curriculum (and relevant assessments) according to their own interests, local contexts and student needs.

Evaluation and assessment frameworks exist in each of the 16 Länder, and the Standing Conference of Ministers of Education and Cultural Affairs (KMK) aims to provide an overarching strategy. Regular assessment of student achievement is a key element of the comprehensive strategy for educational monitoring adopted by the KMK. Overall educational standards are set in primary and secondary education, mainly in mathematics, German, English and French. In 2008, the Länder created comparative examinations to provide nationwide grade-based evaluation in grade 3 (primary) and grade 8 (secondary).

ACCOUNTABILITY

School accountability has become a hot topic for Germany in recent years. While in most Länder this remains a relatively light-touch process, there is some pressure from the KMK to develop more rigorous processes. PISA results have been used to compare performance between Länder, and results in the Abitur may also be used for comparative purposes.

An external evaluation of schools is carried out on a regular basis – every three to six years – in almost all Länder. This may be conducted by a ‘critical friend’ from a local school, or by an external evaluator appointed by the Ministry. The main aim is to monitor and improve the quality of school education, and evaluations may involve the analysis of data and documents, observations (visits to classes, inspections), standardised questionnaires and interviews. The final report is used as a tool for improvement, and/or a trigger for more frequent inspections. Results are not published and there are no league tables.

TEACHERS AND TEACHER TRAINING

Germany’s teachers have the longest pre-service teacher training among all PISA 2012 countries, comprising two phases: a Masters level course (generally five years) in a university, followed by in-service preparation in a school (18–24 months). The university course, heavily influenced by the Bologna declaration, involves gaining Bachelor and Masters level credits in: two science subjects; general and subject-specific pedagogy; and educational theory. Some students will also undertake a school internship during these five years, and some universities may require them to take an exam at the end of their course in order to progress to the next phase. The strong focus on the development of deep content knowledge is considered to be one of the strengths of the German teacher preparation system. In effect this also means that many teachers in Germany are making the choice to enter the profession at ages 18–19, and have a long period of professional formation.

The in-service training phase involves regular observations and feedback from teacher mentors and educators from their university, and at the end of this phase they will need to pass the ‘Second State Exam’ in order to qualify as a teacher. This exam involves presenting on lesson in each subject, an oral exam and a thesis.

Teacher education programmes are designed by universities to follow common standards set by the Standing Conference of Ministers of Education and Cultural Affairs (KMK) and meet regulations set by the relevant Länder. The programmes have to be accredited, and will always require biology, chemistry and physics teacher students/trainees to gain skills planning and performing experiments, as well as handling school-level equipment.

Most school teachers in Germany are employed by the state as higher level public servants or Beamte. This respected status is also held by administrative officials, policemen, prison guards, customs officers, university professors, and by other professionals in the public service and certain holders of political offices. Being Beamte affords many advantages intended to reflect a high expectation of loyalty to the state and commitment to one’s profession. Beamter have permanent tenure and are usually remunerated more generously than ordinary employees, though their salaries tend to vary little from a central, federal salary scheme. In addition, they are exempt from all social security contributions, have a generous health care plan and receive an index-linked pension of around 70% of the final salary paid directly by the state. However, Beamter lack the right to strike and generally work longer hours than ordinary employees.

The teaching workforce is ageing, with a higher proportion of teachers above the age of 50 than the OECD average. Teachers’ salaries are among the highest across OECD countries, and teaching time and class size in primary and secondary schools are above average.

Most of the Länder have laid down the goals of In-Service Training (IST) in their teacher training or educational legislation. All Länder expressly lay down the duty of teachers to undergo IST by law or ordinance, while it is the duty of employers (usually the Ministries of Education and Culture Affairs) to ensure that suitable training programmes are provided.

SCIENCE EDUCATION IN GERMANY

The results of Germany’s participation in the 1995 Trends In Mathematics and Science Study (TIMSS) and 2000 Programme for International Student Assessment (PISA) study shocked the nation. PISA in particular revealed: a comparatively high proportion of German pupils that left school without even basic competences in reading, mathematics and science; a large difference between the lowest achievers and the highest achievers; and enormous differences in achievement and educational opportunities between different social groups and between those of and not of immigration background.² A major reform of the education system was then initiated, in an attempt to reduce social disparities and increase scientific literacy across all social groups. By PISA 2012, Germany’s performance in mathematics, science and reading were all above the OECD average.

² Waldow, Florian. *What PISA Did and Did Not Do: Germany after the ‘PISA-shock’*. European Educational Research Journal, Volume 8 Number 3.

By 2005, National Education Standards (NES) for grade 10 (16 year olds) education in biology, chemistry and physics had been published. The standards cover competences in: content knowledge, scientific inquiry (including experimentation skills); communication (including research and presentation skills); and assessment (including social and ethical implications of science and technology). Work then began on defining the levels of proficiency expected from students in each of these competency areas, although designing instruments to test these levels has proved complex. The Institute for Education Quality Improvement (IQB) based at Berlin's Humboldt University works closely with the state education agencies to implement a national programme of sample-based assessment in the sciences to students in grade 9 across the Länder every three years. The IQB is also coordinating the development of a pool of Abitur examination questions in order to provide greater comparability across the Länder as well as to ensure the alignment of examination tasks with educational standards.

At all levels of the education system, the strengthening of natural science and technical education (MINT – mathematics, information technology, natural sciences, technology) is currently key, but perhaps surprisingly for such a scientifically and technically advanced country, there is still a shortage of young people wanting to take STEM qualifications. Germany has a large and very successful manufacturing sector (24% of GDP compared to the UK's 12%) which has remained relatively buoyant despite the Euro crisis and which demands people qualified in STEM at graduate and technical levels.

STEM INITIATIVES

There appear to be many initiatives to introduce and engage pupils in STEM industries, often running in close collaboration between an individual employer and the local schools. At the federal level too, large multinational companies like Siemens, Volkswagen and Deutsche Telekom have extensive school programmes. The economic context of a large manufacturing sector, economic growth, fewer young people and limited migration provide keen competition among employers for skilled and talented young people.

Activities include:

- Boxed kits which schools can order, such as the Siemens electronics kit for secondary schools, which has a range of experiments.
- Hands-on labs, such as Kieler Forschungswerkstatt at the University of Kiel and DESY Deutsches Elektronen-Synchrotron) lab in Hamburg, which schools can visit and carry out practical workshops, and who make good use of trainee teachers and PhD students in their programmes.
- Large technology fairs such as the Tech-expo in Hannover, which employers may pay to make it possible for schools to attend.
- Visits to local companies such as ZF, a major engineering employer in the Osnabrück area, and visits by companies to schools.

There appear to be many initiatives, at local and at national level, to attract more girls into STEM, especially engineering, and to broaden the range of occupations that girls consider. Of particular note are the following examples:

Girls' Day, whereby businesses, research centres and other institutions put on simultaneous open day events for girls, mainly aged 14–15. In 2016, nearly 9,600 institutions offered about 100,000 places for female students. Since the initiative started, about 1.7 million girls have been involved in the many events organised by companies and organisations in the Girls' Day network, including employers, trade unions and trade associations as well as schools. The aim is to show girls what it is like to work in some of the industries, particularly engineering, which are traditionally less popular for them. Girls apply for places at companies directly through the scheme either independently or with the support of their school. Evaluation shows more than 40 percent of the participating organisations getting enquiries for internships, trainings and university places on Girls' Day, and 33 percent getting applications from women who participated in Girls' Day for internships and trainings. For every fifth organisation, these lead to an employment of female candidates. For the past three years, there have also been 'Boys' Days', to introduce boys to occupations such health and social care.

'Go-MINT', a national pact for women in MINT. Go-MINT is part of the federal government's qualification initiative and was launched in 2008 at the instigation of the Federal Ministry for Education and Research, with the aim of increasing young women's interest in scientific and technical degree courses and attracting female university graduates to careers in business. Pact members participate in a large number of individual interventions, including, for example, cyber-mentoring to give participants an intensive experience of STEM. According to current information from the Federal Office of Statistics and the calculations of the "Go MINT" office, over 33,000 new female students opted for a degree in engineering in the academic year 2011, almost three times the number of new female students in 1995. The picture in mathematics and natural sciences is similar, where the number of new female students has increased by a factor of 2.5 since 1996 to 54,000.

APPENDIX 3:
COUNTRY REPORT:
MASSACHUSETTS



GATSBY

I EVIDENCE GATHERING

This report has been written by John Holman and Beth Jones and is based on the following sources. Further details of the sources are in Annex 1.

- A. Desk research.
- B. Visits to public schools in three different school districts across Massachusetts: John D O'Bryant School of Mathematics and Science (grades 7–12) in Boston on Monday 11 January 2016; Melrose High School (grades 9–12) on Tuesday 12 January; and Chelsea High School (grades 9–12) on Wednesday 13 January.
- C. A visit to the Boston Public School District Monday 11 January 2016.
- D. A meeting with the Massachusetts Department of Elementary and Secondary Education on Tuesday 12 January 2016.
- E. Visit to Museum of Science Boston on Wednesday 13 January 2016.

The visits and meetings in Massachusetts were organised by Professor Hannah Sevia of the University of Massachusetts Boston. She also provided individual expert advice throughout the visit.

2 OUTLINE OF EDUCATION IN MASSACHUSETTS

This is a summary; there is further detail in Annex 2.

The United States of America has a population of 321.5 million people. The Massachusetts state population is 6.7 million.¹ There are 14 counties and 400 school districts in Massachusetts.

The USA has one of the most diverse and least centralised education systems in the world. Federal control of education is anathema because it contravenes states' rights. Even within an individual state there will be many school districts, each with its own education systems and policies: there are about 15,000 school districts in the USA. School districts can vary greatly in their demographic and socio-economic make-up.

There are several layers of administration that sit above individual schools: federal, state, county, school district and school. At each of these levels, curriculum standards are interpreted and reinterpreted, leading to great diversity in curriculum content and pedagogy both between states and within states.

There are both public and private elementary, middle and high schools. In the Boston area, a significant proportion of higher socioeconomic groups use private schools.

Massachusetts has one of the lowest federal funding rates for public schools (5.7%), and a comparatively low state funding rate (39.4%). Therefore, the largest part of funding for schools is locally derived (54.9%). This will differ slightly by school district. Generally, lower income school districts have a higher percentage of state funding. Local funding of schools derives primarily from property taxes, thus is very dependent on the resources and income level of the city or town to which the school district belongs.² Teachers' salaries are determined at the school district level, leading to wide disparities even within the state. School funding is also determined by the number of students attending the school as measured on 1 October. Any student joining the school after this date pressurises a school's finances.

Some school districts, such as Boston, have two tiers of public schools: exam schools and neighbourhood high schools. In Boston, exam schools are attended by the top quarter of students as measured by their performance in a test at the end of elementary school.

Charter schools are publicly funded but are independent of local school district control. They are very similar to English Academies. Charter schools receive a charter to operate from the state department of education and report to the state. There are a growing number across Massachusetts.

There is no consistency across states regarding school leaving age but the majority of states require students to stay in education until the age of 18. It is currently 16 in Massachusetts, although there are moves to change this to 18.

¹ www.census.gov/quickfacts/#table/PST045215/00,25

² Sources: www.nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2015301

MA schools expenditure report: www.profiles.doe.mass.edu/state_report/ppx.aspx

Chapter 70 (state funding allocations per school district): www.profiles.doe.mass.edu/state_report/netschoolspendingtrend.aspx

Schooling runs from Kindergarten (K), (age 4 to 5) to elementary school (age 6 through to age 9/10) to middle school or junior high school (age 10/11 through to age 14/15) and finally on to high school (age 14/15 to age 18). Progression through the school is described by 'grades': Kindergarten through to grade 12 (K–12). Students in grade 9 are known as 'freshmen', grade 10 as 'sophomores', grade 11 as 'juniors' and grade 12 as 'seniors'.

The Massachusetts Department of Elementary and Secondary Education is responsible for student learning standards, licensing teachers and high school leaving assessment (the Massachusetts Comprehensive Assessment System, MCAS). A student's curriculum is in some part based on a 'Common Core' set of standards for mathematics and English language arts (ELA). These standards are proposed at a federal level but adopted by most states in order to receive federal funding. All states are required to administer exams in maths and ELA annually from grade 3 on, and these must be based on the Common Core. No such set of standards exists for science.

However, the Next Generation Science Standards (NGSS) were developed by 26 states, and have been adopted by 15 states so far. Massachusetts has officially adopted an adaptation of the NGSS. Many states have elected not to change their existing science standards at all.

School districts can choose to adapt or ignore these standards, and schools in turn can choose to follow their own curriculum. Control of classroom curricula is ultimately the responsibility of individual class teachers; however, schools, school districts, state and national policy all interact to affect the choices made. Curriculum content is commonly determined by text books and other published learning materials; schools make their own choices about the text books they purchase, which contributes to the differing curriculums between schools.

A school will therefore determine the core curriculum for student study at each grade, but there is an increasing level of choice given to students, particularly around their 'electives' (those subjects beyond a common core of mathematics and ELA) as they travel up through grades.

High ability students can choose to take Advanced Placement (AP) classes; these are college level classes typically taken in junior and senior years. Top colleges would expect students to be taking AP classes, and if students are successful in these courses they can use these credits to contribute to their college degree. AP classes are often a mix of juniors and seniors, as students can choose to take AP classes as electives at any point in high school. AP classes may have relatively small numbers, but they are influential because of the high academic status they carry. AP curricula are set by the College Board. Depending on the course, the College Board specifies the percentage of time spent in the lab, how many labs must be done and the percentage of those labs that must be inquiry based. The College Board has also developed lab manuals with suggested labs to do. Some teachers use these and others don't.³

Students taking a vocational pathway can opt to attend vocational/technical high school at the age of 14 (grade 9). Students in technical schools will be studying core subjects towards achieving their high school leaving certificate (MCAS), i.e. maths, language arts, and science. However, alongside this they will be studying a broad range of context-led programmes related to vocations. These schools have a stronger relationship with the Massachusetts State workforce development board (that links schools and businesses).

2.1 ACCOUNTABILITY AND ASSESSMENT

The Massachusetts Department of Elementary and Secondary Education has the authority to intervene if a school is perceived as failing. This judgement is based largely on the MCAS scores being produced by the school but also on a handful of other factors such as the percentage of courses taught by 'highly qualified' teachers (see section 3.2, science teachers). Schools are graded on a 1–5 scale, with 1 being 'excellence' and 4 being the point at which the state intervenes.

By the end of high school, to achieve their high school diploma and graduate from high school, students must have completed external examinations set by Massachusetts state department for education (MCAS). These examination papers cover mathematics, language arts, and science. For a student to graduate from high school they must achieve a score high enough to pass in all of these papers.

³ www.apcentral.collegeboard.com/apc/public/courses/descriptions/index.html

MCAS tests are written, administered and marked by the Massachusetts Department of Elementary and Secondary Education and their contractors. Administering the MCAS is one of their primary roles. MCAS tests are written question papers and consist of a mixture of multiple choice and short answer questions.⁴

The high school Science and Technology/Engineering (STE) MCAS tests can be taken in any of the following: biology, chemistry, introductory physics or technology/engineering. We heard that there had been an intention for the STE MCAS to consist of a portfolio and practical exam but this was never realised.

Students can retake examinations multiple times; students are therefore often encouraged to take the science MCAS test in grade 9 (first year of high school) to begin accumulating credit towards this assessment as soon as possible. The vast majority of students in Massachusetts do this with the biology test. If a student passes the MCAS in grade 9 in one of the STE subjects, they are not required to take any further science. However, all schools in Massachusetts require students to do three years of science. Some require four. The MCAS science performance level criteria do not contain reference to specific practical skills such as investigative skills or the use of specific practical techniques.⁵

In Massachusetts, students with high school leaving certificates are not graded, but to receive their certificate they must surpass a threshold for each MCAS exam. Papers are graded in four bands: Advanced, Proficient, Needs Improvement and Failing. In order to receive a high school diploma (as opposed to a “certificate of attendance”), students must score a Needs Improvement or higher in one science test.

A high school leaving certificate (or diploma) is a requirement for most ‘next steps’ in education or employment. In addition to the leaving certificate, students will also receive a high school transcript, which contains a record of all classes taken, grades achieved in each subject, Grade Point Average (GPA) and class rank. This transcript is based on teacher assessment, and teachers are free to choose the way in which they assess students throughout the year. When students apply to college they will need to provide their leaving certificate, transcript and also sit additional test such as the standardised SAT or ACT exam. Assessment is a significant part of the American high school system, and top students are aware that they need to consistently perform at a high level throughout school. Multiple-choice and short-answer questions are the norm in US tests.

3 SCIENCE EDUCATION IN MASSACHUSETTS

3.1 NEXT GENERATION SCIENCE STANDARDS

At a federal level, the Next Generation Science Standards (NGSS) have been developed over the last few years and states are in the process of deciding whether to adopt this national standard or not. Massachusetts has chosen not to adopt the standards but to adapt them in a number of ways including specifying standards for individual grades (rather than grade bands) and increasing the number of disciplinary strands to include engineering and technology. At the heart of NGSS is the shift from student led inquiry as stand-alone content to inquiry as practice that is embedded in content. Many teachers we spoke to were already aware of this drive towards improving and increasing the amount of practical work in science as a result of these new standards.

Teachers largely translate/interpret this as a shift from teaching the scientific method to doing more inquiry-based labs. The implication is that classes should integrate experimentation with theory, and should be able to do practical work at any time rather than it being seen as a separate add-on. This was seen by Jake Foster, Massachusetts Director of STEM, as being a significant driver of practical science.

⁴ We only heard of one centrally administered test that was not a written paper – The National Assessment of Education Progress (NAEP) – that provides an overview about the state of education in the United States. For the 2009 NAEP, approximately 2,000 students participated in hands-on tasks as part of the NAEP assessment. Experimental kits were sent out to each participating school, the results of administering such a task can be found here: www.nces.ed.gov/nationsreportcard/pdf/main2009/2012468.pdf

⁵ www.doe.mass.edu/mcas/tdd/pld

3.2 SCIENCE IN THE SCHOOL CURRICULUM

Curriculum

The traditional approach to science education, whereby students study biology in grade 9, chemistry in grade 10 and physics in grade 11, seems to be the norm in Massachusetts.

Historically science teaching would be split into 'class' and 'lab'; however, we observed and heard about a much more integrated approach in all of the schools we visited. This has been facilitated by the NGSS and new classroom design (see section 4.4). High school science curricula can be designed around the attainment targets in preparation for the MCAS tests or schools can derive their own curriculum. We saw examples of both approaches: for example in Chelsea High School teaching staff had designed their own rubric that they felt reflected their preferred pedagogical approach and their specific student population (see Box 1).

Box 1

Chelsea High School – Basic Science

Chelsea High School is the only public High School in Chelsea, a suburb of Boston. It has a very high recently-arrived migrant population in the area, with often over 100 students joining the school throughout the year, many of which do not speak any English. The large majority of students have Spanish as their home language.

Chelsea High School has therefore created a Basic Science course as part of its English Language Programme. We observed a lesson whereby an experiment was used to create a common experience for the students. Students were able to learn about the scientific process while building their language skills as they sought out vocabulary to enable them to describe the experiment. The highly skilled bilingual teacher switched to Spanish when he perceived students were struggling to understand English. In this way, in a single science lesson students learned science, data handling and English.

Beyond the use of the experiment to support language development, it was clear to see the power of a concrete experiment to aid learning of an abstract concept.

We later saw students in their senior year in the top AP Physics class who had begun in these Basic Science Classes.

This curriculum wouldn't be appropriate for every student or every school, but the autonomy and planning freedom given to teachers in this instance had led to a very targeted and effective course.

Schools are free to designate pathways through their curriculum and the organisation of the school day.

SCIENCE TEACHERS

To teach in Massachusetts, teachers need a teaching licence from the state. Teachers must pass a test to demonstrate their competency in their subject area. They can then be awarded a 'preliminary licence' or an 'initial licence'. Preliminary licensure only requires having a bachelor's degree in the subject and passing two Massachusetts licensure tests (language & literacy, and a test in the subject area of licensure), i.e., there are no requirements for having preparation in how to teach. Teachers must progress from a preliminary to an initial licence before the end of five years. An initial licence is awarded after the teacher has undertaken a teacher education programme. Options include:

- Student teaching as part of an education minor, a portfolio submitted to the state through a teacher education programme at university, and getting a science major bachelor's degree.
- Completing student teaching, a portfolio and a master's of education degree from a university after getting a bachelor's degree in science.
- Going through an alternative programme (eg Teach for America).

After five years, an initial licence must be replaced by professional licensure. This is achieved by undertaking professional development. To contribute towards licensure, professional development must include 45 hours of time during a calendar year on a set of learning objectives. This professional licence must be renewed every five years. Licensure renewal is an honour system with random audits of teachers' portfolios (approximately 10% of teachers are audited).

The commonest route into secondary teaching is via a bachelor's degree in science followed by a postgraduate teaching qualification. As there are severe science teacher shortages, particularly in less affluent areas, alternative routes into science teaching are also popular. All science teachers will have a bachelor's degree in a science subject, but after this point the routes diverge.

Career-changers often go through a one-year immersion/internship programme to obtain initial licensure, or teach on preliminary licensure while pursuing initial licensure.

Alternative routes include Teach for America (TfA), a similar programme to Teach First in the UK. Most TfA teachers only teach for 2–3 years and do not stay in the profession. Chelsea High School relies strongly on this programme. Alternative programmes do exist, for example the Boston Teacher Residency (BTR) programme. This is a collaboration between the school district and the University of Massachusetts Boston, which mixes a year-long 'apprenticeship' in the classroom with Masters level coursework.

Teacher pay is determined through negotiations between teacher unions and school districts. It is linked to qualifications (number of credit hours beyond a master's degree) and the number of years spent teaching (up to a maximum of around 10–15 years).

There is no common pay scale for teachers in different school districts. Teachers in the Boston district can earn up to \$30,000 more than teachers in other Massachusetts districts and this leads to greater staff retention and stability in that district. In 2014, the average salary of teachers in Boston was \$90,000, in Chelsea this was \$65,000 and in Melrose it was \$60,000.⁶

Many of the teachers we met had 'common planning time' as part of their contract; one period a week for each subject taught. During this time all teachers in a specific subject are free to plan lessons and to share teaching approaches with colleagues.

Science teachers qualify in a single science discipline and a specific grade band eg physics, chemistry, biology, general science, engineering/technology or earth and space science at grades 5–8 or grades 9–12. This is much more specific than other areas of teaching, for example 'language arts' which encompasses English, arts and humanities subjects. Teachers are allowed to teach in their qualifying discipline and one other subject 'outside their certification'. This causes some issues within science departments when they are creating new elective subjects, or if they have a shortage of teachers in certain science subject.

⁶ www.doe.mass.edu/finance/statistics/salary.pdf

In science, courses with names that are the same as licences must be taught by a teacher with a licence in that area in order for it to be counted as being taught by a “highly qualified” teacher. The percentage of courses taught by highly qualified teachers goes on a school’s report card (determined by federal law) and is part of the formula that is used for determining what levels the schools are.

3.3 SCIENCE BEYOND THE CURRICULUM

Science Fairs, where students work in small groups on a science project (research or experiment), were commonplace in all the schools we visited, although participation rates varied. Final projects are displayed at a fair attended by the local community and judged by a panel of experts. Winners can take part in regional and national competitions. Projects are carried out in students’ spare time, often with the support of a teacher mentor.

Boston Science Museum works with a large number of schools in the Boston School district. They have carried out significant national curriculum development projects, with the support of National Science Foundation funding (for example the development of an engineering curriculum). A significant amount of their work as a museum is beyond the museum walls.

We observed *ad hoc* relationships being built with employers, parents and school alumni. It was the role of senior school administrators to seek out these partnerships and find funding for collaborations. For example, at Melrose High School they were in the process of creating a ‘maker space’ for students to use independently but also to facilitate project based learning.

4 RELEVANT FINDINGS

4.1 TYPES OF PRACTICAL SCIENCE

Practical work was predominately carried out in a single period (45–55 minutes). Only one of the schools we visited had double periods. Class sizes varied, but generally contained a maximum of 31 students in Melrose, 33 students in Boston and 34 students in Chelsea, with chemistry restricted to 24 in some schools. In general, laboratory work was most often shorter and related to theory, either used to begin a topic or summarise work. Practicals used to confirm scientific law and concepts were particularly successful. At its best, we saw such confirmatory lab work being used not only to confirm scientific theory, but also as an opportunity to teach scientific processes such as errors and reproducibility.

Project work, where experiments could be left over several lessons, was less frequent but did occur. Dedicated spaces for this activity were the exception, for example an engineering lab at John D O’Bryant School, which may have restricted the incidence of this type of experiment.

In AP classes, we saw some excellent group work with productive conversations and the use of mathematics to solve problems in physics. In one instance at Chelsea High School, groups of students gathered around white boards in scenes reminiscent of college level work. The teacher reported that it had taken a year to build up the students’ confidence in working in this way, but it was all the more remarkable for the fact that many of the students hardly spoke English when they entered the school. Building the students’ skills and confidence at combining analytical, mathematical and practical skills to solve problems took time and a whole school approach.

We saw fluent use of technology within the classroom including the use of tablets, data loggers and students’ own mobile phones, particularly in physics. We saw students film themselves throwing balls on their phone and then returning to class to track trajectories and plot graphs. Students used associated software packages with ease. Technology was not shoe-horned into the activities but used to enhance and support intended learning.

Fieldwork was infrequent across all sciences, including environmental science. We did not see examples of extended field excursions but we heard classes making use of the school grounds.

4.2 HOW FREQUENTLY?

Given the autonomy of teachers and the variation in student pathways through school, it is difficult to define an exact amount of practical work taking place. However, in high school, we heard that for each science class taken (irrespective of grade) a practical activity would take place approximately once every two weeks. Students taking science courses typically had four lessons of science a week, so approximately 10–15% of lessons contain practical experiments.

Reports from students of their middle school experiences were much more varied, with some students saying that they had done more experiments in middle school compared to high school, and others saying that they had done less. This is a symptom of the autonomy of schools and of individual teachers.

4.3 ATTITUDES TO PRACTICAL SCIENCE

Teachers did not question the existence of practical work as part of science teaching. The teachers we spoke to universally wanted to do more practical work with their students; both because they felt it was important for their students but also because there was a feeling that the 'system' – school district, state and federal – was indicating that practical work was good practice.

Teachers talked to us about the importance of practical work for creating a common experience for their students and to relate science to the 'real world'. Students were arriving into the classroom with very different sets of experiences, and a practical experiment created a shared experience for discussion or reflection on what was being studied.

At both a state level and a school level, we heard officials talk positively about the role and importance of good quality practical work. They found ways to indicate this to schools and teachers through the policies they implemented eg Boston School District protection of the FOSS box scheme (see section 4.5) and the laboratory design guidelines developed by the State of Massachusetts (see section 4.4).

4.4 FACILITIES AND FUNDING

Science teaching spaces in the schools we visited were consistent in design. The spaces were flexible, with moving tables, and practical stations based around the edge of the large rooms. These stations included sinks, gas taps and electric points. Storage cupboards lined the walls and chemistry labs had fume cupboards. Classrooms could therefore function equally well when doing a practical experimental or a solely theoretical class.

This common design is based on guidelines produced by the Massachusetts School Building Authority.⁷ For schools to access funding for new school buildings, they must adhere to these guidelines. The guidelines were produced in conjunction with the state science education department, and have been designed to facilitate integrated practical enquiry into lessons, rather than the historically more common 'lab' sessions that would be taught separately to theory classes.

Teachers predominantly had their own lab spaces, often with adjoining prep rooms. This design allowed teachers to easily store and prepare equipment for each of their practical classes – a necessity with no lab technicians.

Funding was very variable between schools. We heard reports of science departments having no issues with funding through to schools that have no science department budgets at all. It is at the discretion of the school leadership team as to how budgets are distributed in a school. It was common for the science department leads to spend a proportion of their time fundraising and building partnerships to increase available funds.

The disposal of hazardous chemicals was also mentioned as a drain on school budgets. In Melrose High School they have been exploring moving to a 'green chemistry' approach, where volumes of hazardous chemicals are reduced, or not used, to reduce cost of disposal and also the environmental impact of the school.

⁷ www.massschoolbuildings.org/programs/science_lab

In US schools, text books and other instructional materials have an important role in determining what is taught, particularly for teachers less confident in a particular subject area. In some central-control states (such as Texas) text books can only be purchased from a state-approved list. In Massachusetts this is not the case. However, there are around six very large publishers (driven by the choices of central-control states) from which the majority of text books are chosen. Text books are loaned to students free of charge. The cost of text book purchase is separate from other science department expenditure.

4.5 TECHNICAL SUPPORT

As a rule, high schools in Massachusetts (and in the USA in general) do not have technical support staff. There are only a handful of exceptions across the state and even then only one technician for the entire school. In the schools we visited, none of the departments had technical staff. Teachers were required to prepare the equipment and consumables for their lessons. Teachers differed in how they chose to set up experiments; confident teachers gave students greater responsibility for selecting and clearing away equipment than you might see in England. We observed students selecting equipment as it was needed from cupboards around the room during practical activities. Students also explained that they were given a set of basic equipment (eg glassware) at the start of the year and were responsible for maintaining this set. We also saw trays and trolleys organised with sets of equipment ready for students to use, particularly in lower grades.

In Boston elementary and middle schools (grades 7–9), the Boston School District provides all 126 schools with the opportunity to subscribe to the Full Option Science Scheme (FOSS),⁸ a science curriculum supported by boxes of equipment. The FOSS scheme is based on curriculum development carried out by the Lawrence Hall of Science, University of California, Berkeley. Boxes are delivered to schools with teacher notes, student work books and equipment - enough for all students in each grade. Schools rotate which modules they teach so equipment can be moved between schools. The scheme is free to schools and costs Boston Public Schools \$285,000 a year to maintain and replace the equipment. This does not include the cost of the technicians, delivery to schools and the professional development for teachers. Each teacher who chooses to use the scheme attends one professional development day per module (there are two to four modules per grade).

We heard that other schemes similar to this do exist but the approach is becoming less common in the USA. A scheme such as this enables non-specialist teachers in elementary and middle school to use practical work with confidence, and gives students a consistent set of experiences when they travel up into high school.

However, organising this scheme was a significant undertaking, involving a large storage and distribution centre and three centrally employed technicians refurbishing kits as they are returned. Recent, ongoing funding cuts across the school district were threatening the scale of the scheme.

4.6 PROJECT WORK

Project work was not a significant feature of high school science curriculum. Opportunities for extended work occurred beyond the curriculum in science clubs (such as a robotics club in John D O'Bryant) or as preparation for science fairs (see section 3.4). In Chelsea High School, 90% of students take part in the school science fair, each student group works with a teacher mentor. They can therefore have over 100 science projects taking place between November and February (when the fair is held) each year.

Some schools had created specific science pathways in their curriculum, such as the 'engineering pathway' at John D O'Bryant School and the 'STEM pathway' at Melrose High School. Within these pathways, students had more opportunities for extended activities, particularly the engineering pathways. Participants on the pathways were self-selected.

⁸ www.fossweb.com/what-is-foss

Project based learning, a pedagogical approach whereby students carry out a number of activities all focused on a common project theme or problem, was not commonplace across the schools we visited. Melrose High School was beginning to encourage teachers to use this approach in their linked middle school – Melrose Middle School.

4.7 ASSESSMENT OF PRACTICAL SCIENCE

Assessment of practical skills does not form part of the MCAS (section 2.1) assessment, which consists entirely of written questions. However, with new standards being introduced by the Massachusetts education department this year, the MCAS will be changing to reflect the increased role of inquiry in these new standards.

There are multiple assessments throughout high school and no one of these is a dominant driver for teaching and learning. The curriculum is therefore driven by the aspirations of the students in that school. For those students aiming to go to a top college, their focus will be on achieving a high GPA and SAT score, and taking as many AP courses as they can. For lower attaining students, the focus is on high school graduation and achieving the required pass level in the MCAS test.

Individual teachers set their own continuous assessment assignments that feed into the grades that appear on student report cards. Teachers can choose whether practical assignments are included in their class assessments. We saw examples of this happening in several classes across all the schools we visited. There was no common format, but typically the assessment was of a written report or data analysis. However, in one AP physics class in Chelsea High School, we saw marks being awarded to whole groups working together on a practical task.

4.8 TEACHERS' TRAINING AND CPD

All teachers have a statutory right to their own planning time and many have additional common planning time (see section 3.2). This is a necessity given the responsibility teachers have for planning experiments without technicians.

Teachers at Chelsea High School are required to participate in Professional Learning Communities (PLC); groups of teachers in the school with shared skills and interests who work together to solve problems and move the school forward. The groups meet once a week for 80 minutes. The PLC responsible for curriculum development created a new science rubric, which is being implemented across the school. The development was not driven by the MCAS requirements but by the teachers' understanding of what good science teaching should look like. This is an interesting bottom-up approach to curriculum development that resulted in a bespoke curriculum, suited to the student population and with buy-in from the teachers.

It is common for science teachers to attend professional development courses through the summer months. This is enabled by the long holiday (longer than that of English teachers) and the fact that in many cases teachers are paid to attend. Teachers are more likely to attend any professional development course where the provider of the training has acquired funding to pay teachers. When professional development is offered by the school district and it is outside of what is in a teacher contract, teachers must be paid according to the contractually negotiated rate. This differs by school district. In Boston, the negotiated rate is \$49 per hour and in Chelsea it is \$35 per hour.

5 EMERGING LESSONS FOR ENGLAND

1. Massachusetts offers an example of a system that values practical work but is not supported by technicians. It sheds light on likely outcomes of such a system if it came about in England (shorter, more sanitised and less frequent practical work along with increased teacher workload) and the necessary coping strategies (centrally organised 'box schemes', increased teacher planning time, and teachers with their own lab spaces and prep rooms).

Are the capital-intensive solutions seen in Massachusetts really more economical than employing technical staff in schools?

2. With no technicians, teachers in Massachusetts are responsible for identifying all of the health and safety risks of experiments. We believe this may lead, in some cases, to more sanitised experiments, for example the use of safe but unexciting household chemicals instead of chemicals that would show the principles being taught in a more memorable way.
3. We saw a number of lessons that successfully integrated information technology into experimental work. Despite the lack of technicians, technology was used frequently and without fuss by both students and teachers. IT equipment seemed well maintained and in good working order.

What could be done to bring about such a situation in England? Should there be more emphasis on using IT to support hands-on practical work, rather than replacing it?

4. There is widespread agreement across all levels of administration in Massachusetts that practical work is integral to science education. But schools have significant autonomy and ultimately it is the teacher that decides what gets taught in the classroom, and they continue to value practical work. Teachers develop curricula specific to the needs of their students and choose to put practical work at the heart of their lessons.

Could we create a system in the UK that trusts those with the greatest understanding of their students – namely teachers – to design science curriculum? Could professional learning communities support this?

5. The best examples of practical science that we saw used experiments to confirm scientific laws and concepts that has already been introduced, rather than using the practical to introduce the concepts. This made it possible to use the experimental results to reflect on scientific methodology and discuss statistical aspects of the data, in addition to confirming theory. However, it was confirmed that the critical weakness in making effective use of practical science is the absence of 'sense making' – following up experiments with discussion and reflection. This strikes a chord with experiences in England, where commentators note the value of teachers spending time discussing the results of experiments with their students, but note that this is often precluded by the time available.
6. The deep conviction of the teachers that we met of the importance of practical science helps to reinforce the conjecture that, *as the virtual world becomes more accessible and realistic, authentic experience in the real world becomes more, rather than less, important.*

ANNEX I: SOURCES OF EVIDENCE

A. DESK RESEARCH.

Main sources (accessed November 2015)

www.nces.ed.gov/programs/digest/d01/fig1.asp

www.profiles.doe.mass.edu/profiles/general.aspx?topNavId=1&orgcode=00000000&orgtypecode=0&

www.doe.mass.edu

www.doe.mass.edu/frameworks/current.html

www.doe.mass.edu/frameworks/scitech/1006.pdf

www.masslifesciences.com/resources/stem

www.massschoolbuildings.org/programs/science_lab

www.massschoolbuildings.org/programs/science_lab/guidelines

www.massscienceteach.org

www.msela.org

www.nytimes.com/2015/11/22/us/rejecting-test-massachusetts-shifts-its-model.html?mcubz=0

[www.oecd.org/pisa/keyfindings/PISA2012_US%20report_ebook\(eng\).pdf](http://www.oecd.org/pisa/keyfindings/PISA2012_US%20report_ebook(eng).pdf)

www.en.wikipedia.org/wiki/School_district

B HALF DAY VISITS TO HIGH SCHOOLS ON 11 JANUARY, 12 JANUARY AND 13 JANUARY 2016.

John D'O Bryant School of Mathematics and Science,

55 Malcolm X Blvd, Roxbury, MA 02120. As an exam school, it requires high test scores for entry (first of three in the school district); grade 7–12, approximately 1,400 students.

We met the Director of Science, a chemistry teacher, a middle school science teacher and eight teachers from the high school and middle school at a roundtable discussion. We observed and spoke to students in three science classes (AP environmental science, AP chemistry, grade 8 chemistry).

Melrose High School,

360 Lynn Fells Pkwy, Melrose. Grade 9–12 (also affiliated middle school next to high school building). Approximately 980 students.

We met with the Director of Science (who accompanied us throughout the day), a roundtable of approximately 15 teachers from across different disciplines and grades including the Principal of the middle school, observed and spoke to students in 7 science classes (AP environmental science, two honours chemistry classes, AP biology, honours physics, AP chemistry, and AP physics) and toured the middle school science facilities.

Chelsea High School,
299 Everett Ave., Chelsea. Only public high school in Chelsea. About 1,600 students.

We met with the Science Department Head and the Director of the Bridge Academy (a English Language Learners (ELL) faculty), observed two lessons and spoke with a group of 11 students from a range of grades.

**C. A VISIT TO BOSTON SCHOOL DISTRICT AND FOSS BOX DISTRIBUTION CENTRE
ON 11 JANUARY 2016.**

Lead contact: Pam Pelletier – Director of K–12 science/technology, Boston Public Schools

**D. A MEETING WITH THE MASSACHUSETTS DEPARTMENT OF ELEMENTARY AND SECONDARY
EDUCATION ON TUESDAY 12 JANUARY 2016.**

**E. A MEETING WITH CHRISTINE REICH, DIRECTOR OF EXHIBIT DEVELOPMENT AND
CONSERVATION AT THE MUSEUM OF SCIENCE BOSTON ON WEDNESDAY 13 JANUARY 2012.**

ANNEX 2: EDUCATION IN MASSACHUSETTS – A BRIEFING NOTE

USA STRUCTURE

The USA is a federal republic made up of 50 states. It has a population of over 320 million (the third most populous in the world). It is one of the world's largest economies.

The United States Constitution itself reflects the desire to encourage scientific creativity. It gives the United States Congress the power "to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries."^[1] This clause formed the basis for the US patent and copyright systems, whereby creators of original art and technology would get a government granted monopoly, which after a limited period would become free to all citizens, thereby enriching the public domain.

Part of America's past and current pre-eminence in applied science has been due to its vast research and development budget, which at \$401.6bn in 2009 was more than double that of China's \$154.1bn and over 25% greater than the European Union's \$297.9bn

The No Child Left Behind Act of 2001 (NCLB) has just been replaced by Every Student Succeeds Act (signed 10 December 2015). NCLB linked school funding to student performance on national standardised tests. Students will continue to take annual tests between the third and eight grade.

MASSACHUSETTS STRUCTURE⁹

There are 14 counties in the state of Massachusetts. We visited Suffolk County on the West coast. There are four school districts in Suffolk county:

- Boston.
- Chelsea.
- Winthrop.
- Revere.

USA EDUCATION SYSTEM

There are two broad school funded routes: private and public schools. Public schools (state funded) are attended by 90% of students (K–12).

Elected local school boards set public school curricula, budgets, and policies for school districts. School districts are a specialist form of local government (fiscal and administrative independence from county, township and municipal governments). The school board appoints a superintendent who is usually an experienced public school administrator, to function as the district's chief executive for carrying out day-to-day decisions and policy implementations.¹⁰

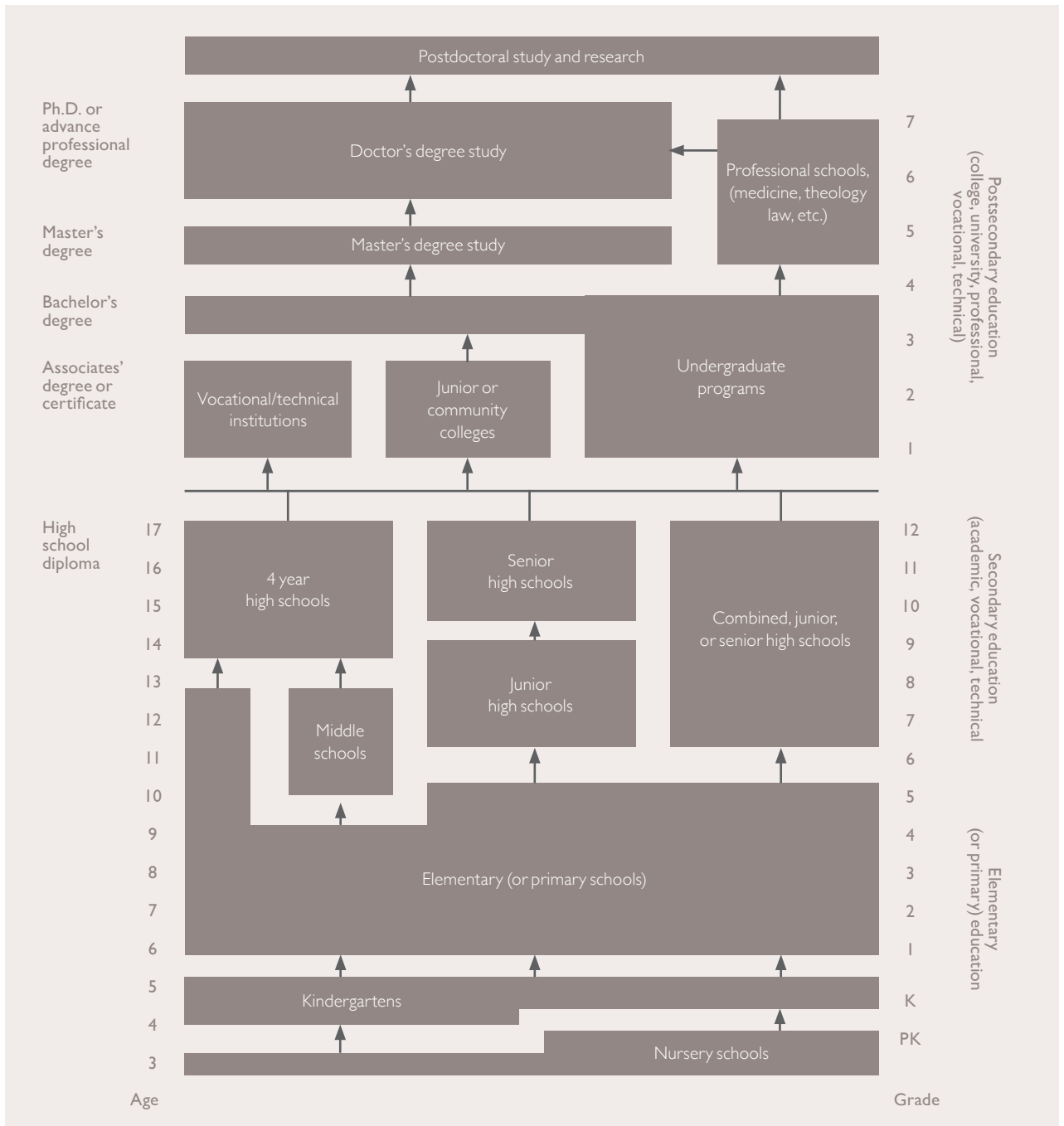
State governments set overall standards and generally set mandated standardised tests and supervise colleges and universities.

The compulsory education age varies between states. In Massachusetts education is mandatory between the ages of 6–16.

⁹ www.profiles.doe.mass.edu/profiles/general.aspx?topNavId=1&orgcode=00000000&orgtypecode=0&

¹⁰ Wikipedia www.en.wikipedia.org/wiki/School_district

Figure I: The Structure of Education in the United States¹¹



¹¹ National Association of Education Statistics, USA www.nces.ed.gov/programs/digest/d01/figl.asp

MASSACHUSETTS EDUCATION SYSTEM – OVERVIEW

In PISA 2012, Massachusetts, Connecticut and Florida were oversampled in order to be able to distinguish their results from the overall USA position. Taken separately, Massachusetts scored significantly higher than the US average and higher than either Florida or Connecticut, achieving a maths score of 514 (similar to Germany).¹² Massachusetts is seen as an example of educational reform (namely through the introduction of their Education Reform Act in 1993) that successfully led to radical educational improvements.

In October 2013, there were 408 operating school districts in Massachusetts, with 1,860 public schools (1,154 primary, 313 middle schools, and 393 secondary schools). There were also 81 charter schools. There are close to a million students enrolled across all the grades of education. There is a broad range of ethnicities within the school system (17.9% Hispanic, 8.7% African America, 6.3% Asian, with 63% white).¹³

MASSACHUSETTS CURRICULUM

The state of Massachusetts sets its own curriculum framework. Students develop a core of knowledge – a set of basic facts and information that can become the foundation for more advanced work. This approach was influenced by the US academic, ED Hirsch, who argued that students who possessed a broad base of key knowledge were much better equipped to understand and interrogate more complex ideas. Massachusetts sets its students such targets – with its “common core of learning”, introduced as part of education reform legislation in 1993. This means that all students in state schools in Massachusetts have a curriculum that sets out the core knowledge they would be expected to have learnt in each age group. Several hearings (involving thousands of individuals) established what the content should be for the common core.

Each of the subject frameworks in this curriculum has an overarching purpose. For example, in the 2006 Science and Technology/Engineering curriculum framework¹⁴ it states;

Investigations in science and technology/engineering involve a range of skills, habits of mind, and subject matter knowledge. The purpose of science and technology/engineering education in Massachusetts is to enable students to draw on these skills and habits, as well as on their subject matter knowledge, in order to participate productively in the intellectual and civic life of American society and to provide the foundation for their further education in these areas if they seek it.

The frameworks also set out specific pieces of information or ‘learning standards’. For example, there are four learning strands within the science and technology curriculum, each of which is broken down into specific statements (with examples of activities and extensions) for each grade (K–12). Progression across the grades can be seen in the documents within each of the learning strands.

Curriculums in every country or school system have expectations for levels of achievement, but the Massachusetts system is characterised by a particular focus on lists of specific pieces of information.

MASSACHUSETTS ASSESSMENT

Significant funding accompanied the changes that occurred in 1993. This includes funding directly to schools but also the development of new assessments associated with new standards.¹⁵

The Massachusetts Comprehensive Assessment System, commonly shortened to MCAS, is the Commonwealth’s state-wide standards-based assessment programme. State and federal law mandates that all students who are enrolled in the tested grades and who are educated with Massachusetts public funds participate in MCAS testing.

For students to earn a high school diploma, they must meet the Competency Determination (CD) Standard. The CD Standard states that pupils must pass both the English language arts and mathematics portions of the grade 10. Beginning with the graduating class of 2010, students are also required to pass a Science and Technology/Engineering Test.¹⁶ This test does not cover all the sciences: it can be one of biology, chemistry, introductory physics, or technology/engineering.

If students do not pass the English language and maths components to the required level (240 points), they can score a lower number of points if they also fulfil the requirements of an Educational Proficiency Plan (EPP). This is a broader assessment that takes into account a wider range of student work including teacher input, a requirement to succeed in grade 11 and 12 courses and an annual assessment to ensure students continue to make progress.

¹² [www.oecd.org/pisa/keyfindings/PISA2012_US%20report_ebook\(eng\).pdf](http://www.oecd.org/pisa/keyfindings/PISA2012_US%20report_ebook(eng).pdf)

¹³ www.profiles.doe.mass.edu/profiles/general.aspx?topNavId=1&orgcode=00000000&orgtypecode=0&

¹⁴ www.doe.mass.edu/frameworks/current.html

¹⁵ www.nytimes.com/2015/11/22/us/rejecting-test-massachusetts-shifts-its-model.html?smprod=nytcore-iphone&smid=nytcore-iphone-share&_r=2

¹⁶ Massachusetts Department of Education www.doe.mass.edu

Students take different tests according to their grade level. In addition to these tests, students may be required to take 'try-outs' and pilot tests.

Students are also encouraged to complete Massachusetts Programme of Studies (MassCore) before leaving high school. The MassCore programme includes four years of English; four years of mathematics; three years of lab-based science; three years of history; two years of the same foreign language; one year of an arts programme; and five additional 'core' courses such as business education, health, and/or technology. MassCore also includes additional learning opportunities including AP classes, dual enrolment, a senior project, online courses for high school or college credit, and service or work-based learning.

In November 2015, the Massachusetts State Education Board rejected the national tests based on the National USA 'Common Core' standards. Massachusetts will embark on developing a new test based on the Core Standards and the Partnership for the Assessment of Readiness for College and Careers (Parcc).¹⁷

SCIENCE EDUCATION

Science and technology education is present in the curriculum from Kindergarten through to the end of high school.

Within the 2006 Science and Technology/Engineering curriculum¹⁸ both 'nature and philosophy of science and technology' and 'inquiry, experimentation, and design in the classroom' are described.

There are four learning standards:

- Earth and space science.
- Life science (biology).
- Physical sciences (chemistry and physics).
- Technology/engineering.

Each strand's learning standards are grouped into four grade spans:

- Grades Pre K–2.
- Grades 3–5.
- Grades 6–8.
- High School.

INQUIRY, EXPERIMENTATION AND DESIGN IN THE CLASSROOM

From the Science and Technology learning standards: ¹⁹

"Engaging students in inquiry-based instruction is one way of developing conceptual understanding, content knowledge, and scientific skills. Scientific inquiry as a means to understand the natural and human-made worlds requires the application of content knowledge through the use of scientific skills. Students should have curricular opportunities to learn about and understand science and technology/engineering through participatory activities, particularly laboratory, fieldwork, and design challenges.

Inquiry, experimentation, and design should not be taught or tested as separate, stand-alone skills. Rather, opportunities for inquiry, experimentation, and design should arise within a well-planned curriculum. Instruction and assessment should include examples drawn from life science, physical science, earth and space science, and technology/engineering standards. Doing so will make clear to students that what is known does not stand separate from how it is known."

The curriculum identifies investigative skills and progression through all stages (K–12), beginning with simply recording what they observe in Kindergarten through to carrying out extended independent experiments (potentially with the support of an external mentor) in the last two years of high school. The framework also lists Scientific Inquiry Skills (SIS) standards.

SIS1. Make observations, raise questions, and formulate hypotheses.

SIS2. Design and conduct scientific investigations.

¹⁷www.nytimes.com/2015/11/22/us/rejecting-test-massachusetts-shifts-its-model.html?smprod=nytcore-iphone&smid=nytcore-iphone-share&_r=2

¹⁸ www.doe.mass.edu/frameworks/scitech/1006.pdf

¹⁹ www.doe.mass.edu/frameworks/scitech/1006.pdf

SIS3. Analyse and interpret results of scientific investigations.

SIS4. Communicate and apply the results of scientific investigations.

SCIENCE EDUCATION INITIATIVES

Massachusetts school building authority ²⁰

In 2011/12 a sixty million dollar science laboratory fund was made available to schools to focus on the development of prototype designs for science labs. Guidelines for good quality facilities were also released. ²¹

The Massachusetts Science Education Leadership Association (MSELA) ²²

MSELA was formed in 1968 to develop science education leadership for K–16 school systems. MSELA members have a strong interest in student learning, curriculum design, uses of technology, professional development, assessment, science as inquiry, science education reform, and state and national standards and frameworks. MSELA is an affiliate of the National Science Education Leadership Association (NSELA) and is an associated group of the National Science Teachers Association (NSTA). MSELA has over 200 members who hold a variety of science education leadership positions.

The Massachusetts Life Sciences Center ²³

The Massachusetts Life Sciences Center is actively involved in promoting STEM education across the Commonwealth. The council's goal is to ensure that all students are educated in STEM fields to enable them to pursue post-secondary degrees or careers in these areas, as well as raise awareness of the benefits associated with an increased state-wide focus on STEM.

The MLSC is a co-sponsor of the annual Massachusetts STEM Summit, which addresses the entire education spectrum, workforce development, economic development and other key policy issues faced by the Commonwealth. The MLSC provides funding related to STEM projects at high schools, community colleges and universities through the Center's *Capital Programme*.

The MLSC also reimburses life sciences companies for internships related to STEM.

The Massachusetts Association of Science Teachers ²⁴

The Massachusetts Association of Science Teachers (MAST) is a professional organisation dedicated to improving science education at all levels. MAST is the state chapter of the National Science Teachers Association (NSTA) and acts as the representative on national and state policies concerning science education.

²⁰ www.massschoolbuildings.org/programs/science_lab

²¹ www.massschoolbuildings.org/programs/science_lab/guidelines

²² www.msela.org

²³ www.masslifesciences.com/resources/stem

²⁴ www.massscienceteach.org/

APPENDIX 3:
COUNTRY REPORT:
NETHERLANDS



GATSBY

I EVIDENCE GATHERING

This report has been written by John Holman, Beth Jones and Ginny Page and is based on the following sources. Further details of the sources are in Annex 1.

- A. Desk research.
- B. A consultation seminar on 1 December 2015 in Amsterdam with teacher trainers.
- C. Visits to two general academic schools, Amsterdam Lyceum (VWO) and Damstede School (VWO/HAVO), in Amsterdam on 1 December 2015 and to a general academic (VWO/HAVO) school (St Bonifatius College) in Utrecht on 2 December 2015.
- D. A visit to Jet-Net, an organisation promoting STEM education by brokering school-industry partnerships, in The Hague, on 30 November 2015.

The visits and seminar in the Netherlands were organised by Professor Harrie Eijkelhof of the Freudenthal Institute for Science and Mathematics Education, University of Utrecht. He also provided individual expert advice, as did Dr Ed van den Berg of the Amsterdam Free University.

2 OUTLINE OF EDUCATION IN THE NETHERLANDS

This is a summary; there is further detail in Annex 2.

The Netherlands is a small but densely populated country of 17 million people, 84% of whom live in urban areas. Unemployment is relatively low, GDP per head is the 12th highest in the world and income inequality is relatively low. There is high ethnic diversity.

There is a mix of private and public schools, but all are funded by the government. Schools have well-established, high levels of autonomy, combined with relatively moderate, if increasing, procedures for external accountability. The curriculum structures can vary widely between schools.

Secondary and tertiary education in the Netherlands is highly selective and structured. After primary school, students transfer to one of three secondary streams: pre-university (VWO), general academic (HAVO) and pre-vocational (VMBO). The stream that they enter is mainly determined by their performance in a national test, though parents' preferences and primary schools' judgements are also taken into account.

VWO and HAVO students are usually taught as separate streams in the same school, with VWO following a more extended curriculum than HAVO. VWO/HAVO schools may also include a VMBO stream, or VMBO students may attend a completely different school dedicated to pre-vocational education. Within the VMBO stream, there are varying blends of general academic and pre-vocational education, depending on students' age, interests and aptitudes.¹

After school, VWO students usually go to a research-intensive university (WO), HAVO students to a technical university (HBO) and VMBO students to a vocational college (MBO – like an FE college) to prepare for a specific job. Of course, there are exceptions to all these rules, and transfer between the streams is possible (though usually involves additional time).

¹ The more academic sub-streams within VMBO are sometimes called MAVO.

2.1 ACCOUNTABILITY AND ASSESSMENT

Schools in the Netherlands are expected to prioritise student performance in examinations, but there is some interesting work going on to broaden the accountability measures beyond examination results. The *Vensters voor Verantwoording* (Window of Accountability) has been produced by the Dutch Council of Secondary Education,² providing a readily-understood dashboard of around 20 performance indicators, some of which use data provided by the Ministry, some using local data from the school.³ Several indicators relate to examination results, but others are more general: for example, there is a student satisfaction indicator.

The school-leaving assessment at the end of the final year consists of a school examination and a national written examination, the two being equally weighted.

School exams are set by the school itself. School exams can combine oral, practical and written assessments but are always marked by the student's own teacher. The national exam, set by the Ministry of Education, has the same questions for all pupils in a given type of school or stream (VWO, HAVO etc) and for a particular subject. These externally set exams are also marked by practising teachers who meet regionally to ensure consistency. If marks in the school exam significantly exceed those in the national exam, an inspection may be triggered.

There is a school inspectorate (called the *Inspectie van het Onderwijs*) which monitors schools' compliance with regulations. All schools are inspected every 5–7 years, but more frequently if there are issues. Inspectors can categorise schools as 'weak' and ultimately close them down. Only a small number of schools (~3%) are categorised as weak.

3 SCIENCE EDUCATION IN THE NETHERLANDS

3.1 STEM

The Netherlands has a 'STEM agenda', strongly supported by the government for more than 10 years and involving nationally co-ordinated projects across all ages implemented through regional structures and local partnerships. The Platform Bèta Techniek is driven by employers' needs for more people with qualifications in science, technology, engineering and mathematics, as in the UK, with a particular need for technical skills. There is a target⁴ to get 4 out of 10 workers having STEM qualifications (the current ratio is 2.5 out of 10). Schools can choose to participate in projects of Platform Beta Techiek. This grants them access to a range of both pupil-focused initiatives and teacher CPD.

As well as needing more STEM qualified people overall, there are problems of under-participation by certain groups. In higher education, females are strikingly under-represented in certain subjects such as physics and engineering.⁵ Ethnic minorities tend to avoid technical subjects in favour of finance and business, because they often associate them with parents' low-level jobs from which they want their children to escape.⁶

One of the Platform's STEM-related initiatives to get employers into schools, and school students into the workplace is Jet-Net. Jet-Net was initiated by a group of CEOs from large STEM corporations and is designed to increase the appeal of STEM subjects by adding context through links with universities and industry. A range of initiatives are supported by Jet-Net but at its core is a formal partnership between schools and employers in close proximity to each other. They work together to build experiences for pupils and STEM industry.

² The Secondary Education Council, *VO-Raad*, is a group made up of the principals and Boards for all the VWO-HAVO schools in the Netherlands. There are similar Councils for other types of schools. There is no English equivalent to these councils, which seem to serve a valuable purpose in securing consensus for action among school leaders. www.vo-raad.nl/contact-helpdesk/english-summary

³ An example of this dashboard: www.wiki.schoolvo.nl/info/venster/www.schoolvo.nl/index.html

⁴ Nationaal Techniek Pact (2013) (National agreement on technology, signed by industry, trade unions, school organisations, ministries and regional governments).

⁵ Booy, C., Jansen, N., Joukes, G. & van Schaik, E. *Trend Analysis: Gender in STEM Higher Education*. Amsterdam (2012). VHTO.

⁶ Hiteq (2008). Kenmerkend vmbo www.hiteq.org/cms/publish/content/downloaddocument.asp?document_id=134 Geraadpleegd op 23 maart 2009] and Neuvel, J., Esch, W., van, Van vmbo naar mbo: doorstroom en loopbaankeuzes, eco, januari 2010.

Jet-Net uses a subscription model of funding from its corporate partners with companies with over 1,000 employees paying 10,000 Euros per year. Jet-Net are in the process of moving to a regionalised model with large employers acting as coordinating bodies for school engagement activity across their province. About a third of VWO and HAVO schools are involved, and there is a waiting list. There is a Jet-Net Junior Hubs programme for primary schools. Schools working with Jet-Net have seen a 5% increase in students choosing to take STEM pathways at 14.

3.2 SCIENCE IN THE SCHOOL CURRICULUM

Curriculum

The Dutch Ministry of Education sets a general national curriculum framework. The framework outlines suggested time allocation and attainment targets (what students should know and be able to do) for subject areas and cross-curricular topics. However, schools, and to a great extent individual teachers, are free to teach the core subjects in any way they see fit, provided they meet the attainment targets. 60% of the national curriculum is assessed in the national written exam (based on detailed syllabuses provided by a national examination board). The rest of the curriculum is assessed at school level (based on very broad attainment targets which leave a lot of freedom to schools). The 60% proportion assessed nationally might increase in future.

In the lower years (years 1 to 3, ages 12 to 15) of secondary school, all pupils follow a general curriculum. In VWO and HAVO, these first three years include all three sciences generally introduced at different stages, usually with biology first followed by physics and chemistry. In the upper years (years 4 to 5/6, ages 15 to 17/18) of HAVO and VWO, pupils choose one or more of four subject combinations (*profielen*).

- Science and technology.
- Science and health.
- Economics and society.
- Culture and society.

In VWO, about 60% of students choose science profiles; in HAVO it is about 40%. Each profile includes a number of compulsory subjects: six for HAVO and seven for VWO. Besides their chosen specialised subjects, all HAVO and VWO students take a number of compulsory subjects:

- Physical education and culture & the arts.
- A project relating to their specialised subjects, the *profielwerkstuk*.
- Mathematics (all VWO pupils).

Thus many HAVO/VWO students are able to drop science completely at age 14, or choose a narrow science 'profile' which is either health or technology orientated. However, they may also combine profiles, add non-compulsory options such as the interdisciplinary 'Nature, Life and Technology (NLT)' course, and can supplement their scientific studies with an extended project.

Science teachers

There are several routes into teaching. The route depends on the point at which you decide to become a teacher and the level at which you want to teach. The most common routes for teachers in senior secondary education are via a masters degree in your subject discipline, followed by a one year masters course in education delivered by a higher education institution, or via a two-year masters course after the bachelors degree. Teachers in junior secondary education follow a four-year programme at a teacher training college.

4 RELEVANT FINDINGS

4.1 TYPES OF PRACTICAL SCIENCE

We heard teachers describe practical work of all different kinds, ranging from short experiments linked to the theory being taught, through to longer, assessed investigations, and to major 80-hour projects – the *profielwerkstuk* (section 4.6). Teachers in Dutch schools enjoy considerable autonomy, so the amount and type of practical work they do depends on their inclination. This may be influenced by their subject specialism, their own experience, and even their relationship with their students. One very experienced deputy head told us that teachers who like to be in control of the class might not do much practical work because it “means a bit of chaos”.

Several teachers in the schools we visited spoke deprecatingly of ‘cookbook’ experiments, but we got the impression (from Ed van den Berg and others) that these were quite common in some other schools (often based on worksheets). On the other hand, we heard that teachers are doing increasing numbers of practical investigation-type activities, though one teacher explained that this depended on whether they were teaching VWO or HAVO students, as the latter did best if given more instructions. All teachers agreed the importance of integrating practical with theory, but acknowledged that this was not always easy to do when lessons last under an hour (typically 50 minutes).

We saw several examples of individual teachers taking the initiative to innovate in their use of practical work. The ‘Da Vinci’ programme led by Kees Hooyman at St Bonifatius College seems exemplary (and probably exceptional) in the way it encourages students to devise their own solutions to problems rather than simply following ‘cookbook’ instructions. At Amsterdam Lyceum, Joren Nooij told us how he has drawn on research and CPD to develop a programme of study for physics where students plan experiments before they start, to encourage their understanding of scientific processes.

4.2 HOW FREQUENTLY?

It is difficult to give a reliable estimate of the frequency of practical science in Dutch schools because it varies widely between teachers, between schools and between age groups. We heard that the minimum in the schools we visited might be as little as once a month, but the maximum could be 40%. One head of science told us he had tried getting his teachers to commit to spending 25% of lesson time on practical work, but did not succeed. He estimated 15% was the average.

We can be fairly confident that:

- Practical work is more prevalent in lower secondary (years 1 to 3) than upper secondary.
- It is also more frequent in physics and chemistry than biology in the upper years.
- Even in biology, there is relatively little outdoor fieldwork taking place at any stage.
- In upper secondary, the majority of practical science comes through student assignments (which may or may not be assessed) and in the extended project (if a scientific one is chosen). Students undertake much of this work in their own time.

We heard mixed reports about whether there was a trend to increase, or decrease, the proportion of practical work. Where it was increasing, it tended to be as a result of teachers deciding to invigorate their teaching through new, practical-rich approaches and being given the support of their senior management to do so. One teacher felt that the only threat to practical work in their school would be if funding from Government initiatives and regional schemes dried up in the future.

4.3 ATTITUDES TO PRACTICAL SCIENCE

All the teachers we met told us that practical science is important to both learning and to students' attitudes to science. However, in practice, as in England, preparation for national exams has a significant influence in upper secondary, and finding time in the curriculum is a challenge.

Students told us that they enjoy practical science because it helps them to understand theory and it provides a link to 'real life'. They seem relatively unconcerned whether the skills they gain through practical work are important for future study or work. But as in England, they find practical assignments much less enjoyable when they are formally assessed.

In all the schools we visited, we were told that it is common for upper secondary students to come back to do experiments outside timetabled hours, working collaboratively on practical projects and asking for support directly from technicians. This gave an impression of comparatively high degrees of informality in science teaching, yet underlying this freedom there are formal and highly organised structures and an expectation that pupils will conform. Co-operation between pupils is encouraged: we saw a class of pupils taking a test in collaborative groups of three.

4.4 FACILITIES AND FUNDING

All three of the schools we visited had facilities for practical science comparable to good schools in England, with high levels of satisfaction from staff and students. In one of the three schools, a teacher reported the availability of laboratories as a limiting factor on practical science, and in another a couple of students felt that there was insufficient kit for equitable whole-class practicals. Schools make a distinction between 'full laboratories' - fully equipped for a specific subject (for example with a fume cupboard or mass spectrometer) - and 'science classrooms' which have moveable furniture, and workstations supplied with water, electrical sockets and sometimes gas, so that a range of experiments can be done in them. However, we were told that new schools may be being built with more limited laboratory facilities. It was common across all three schools visited for there to be fewer fully equipped biology laboratories.

Class sizes in lower secondary average around 25, with 32 the maximum, so this is not a constraint on the scope for practical work. The students we observed usually worked in groups of two (older students) or three (younger students) for practicals.

All the schools we visited had specialist preparation rooms in which laboratory technicians store and prepare apparatus. These workspaces were well-lit, well-organised and close to the relevant teaching rooms, as well as to flexible laboratories dedicated to student project work. In one school, we observed open plan preparation rooms that merged into the back of the classroom, in another we saw a large workshop space specifically for developing and maintaining equipment.

Science departments (Physics, Chemistry and Biology) have delegated budgets for equipment and materials. We were told of budgets in the range 1,200–5,000 Euros per annum (compared with budgets of a few hundred Euros for non-science subjects in one school). We were told on several occasions that requests for new equipment were rarely, if ever, unsuccessful. Text books are loaned to students free of charge and come out of a separate budget.

The use of ICT seems well developed. Most schools have specialist software and equipment for data logging (such as 'IP Coach'), and they seem to use it regularly, though more in physics than in chemistry and biology.

4.5 TECHNICAL SUPPORT

Dutch schools are well provided with science technicians, who usually work part-time. The schools we visited had at least one technician for each separate science. The technicians we met were generally confident and proud of their role in the school. They are appreciated and relied on by teachers. However, although VWO and HAVO schools have science technicians, VMBO (vocational schools) do not because most of their teaching is vocational and teachers have a vocational background.

Technicians play an active role in helping the teacher and students in lessons, probably more so than in the UK. They are particularly valued as a support for the final year project (section 4.6) for which they manage the use of dedicated laboratories and provide technical advice to students. They may also help with the assessment of students' practical assignments in the school exam.

As well as preparing experiments, technicians do all the ordering of equipment.

4.6 PROJECTS: THE *PROFIELWERKSTUK* (PWS)

All final year students in VWO and HAVO must complete an 80-hour independent project in a subject related to their profile specialism. The work is spread over several months between the end of the penultimate year and January of the final year, and in some schools the timetable is suspended for a week while students work on their projects. This means that many students in the 'science and technology' and 'science and health' profiles carry out science projects, which often include practical work.

The effect of this is that a great deal of science project work goes on in Dutch schools, often in small collaborative groups of two or three. Students are expected to contribute 80 hours of work to their PWS irrespective of whether they work on their own or in a group. Depending on the size of the cohort, there might be about 20 projects in the final year which often involve practical science, hence the need for the schools we visited to have dedicated space for students to work on their projects. During the project period, a lot of the laboratory technicians' time is spent supporting students' project work. We saw some impressive projects in all three of the schools we visited (see box). The students we spoke to took their projects very seriously, and this appears to be typical.

Students are systematically prepared for their projects, and may do practice experiments. Projects can be done with support from, for example, industry or a university. Some universities have telephone 'helpdesks' dedicated to supporting students' *profielwerkstukken*.

Science projects in the Netherlands: the *profielwerkstuk*

Some examples we saw:

At Damstede School, two female students using 'IP Coach' data-logging kit to analyse harmonics in the human voice to see if there is a detectable difference between ethnic groups.

At Damstede School, a male student devising new experimental work for the school to use with younger students, linked to the germination of seeds.

At Amsterdam Lyceum, a female student investigating the psychological state of kidney patients preparing to undergo dialysis.

The critical assessment for Dutch students is the school-leaving assessment at the end of the final year, which consists of a school examination (which can comprise a combination of different assessments) and a national written examination. There is no practical assessment in the national examination apart from those written questions set in a practical context.

4.7 ASSESSMENT OF PRACTICAL SCIENCE

Practical skills must be assessed as part of the school exam, the weighting being for the school to determine – 20% seemed typical although this can vary between subjects in the same school. At Damstede, the assessment is based on a written report of a practical assignment (assessed by the teacher) and observation of the student's work by the teacher or technician. This facilitates teamwork between pupils even during assessed practicals – we saw a class of pupils taking a test in collaborative groups of three.

Practical skills may also be assessed as part of the final year project, the *profielwerkstuk*.

4.8 TEACHERS' TRAINING AND CPD

As in England, there are multiple routes to becoming a teacher in the Netherlands, broadly either undergraduate courses, post-graduate courses or salaried Education Traineeships which allow trainees to conduct specialist modules in areas such as assessment and curriculum development.

During their initial training, Dutch teachers receive some dedicated training in practical work, though this seems to vary quite widely between institutions and will depend on which route they are following. Practical work training might include kitting out a new science lab, identifying plants in order to conduct fieldwork, use of public facilities such as zoos and farms for science inquiry, using computers and data-loggers as part of practical work, how to work with lab technicians, maintaining a safe environment, and engaging with research literature. However, one experienced trainer on a postgraduate teacher training course told us that, as he has no labs available to him, he is limited to undertaking practical sessions with microscale equipment, or leaving practical work to teacher mentors in placement schools.

The importance of continuing professional development (CPD) is acknowledged but uptake by teachers seems to depend on the individual teacher and school (as in England). We were told at St Bonifatius College that, if a teacher wants CPD, it is never refused. There are dedicated CPD courses on practical science, organised by the science teachers' association, NVON (the equivalent of the ASE).

5 EMERGING LESSONS FOR ENGLAND

1. In many ways, the Netherlands provides a useful comparator for England where practical science is concerned. Although the selective Netherlands system is very different from the English comprehensive school (where almost all students follow a similar programme of science study up to 16), the standard of laboratory facilities, equipment and technician support are similar, and there is a similar enthusiasm among teachers in successful schools for practical work. The best Dutch schools provide a model for what is possible in practical science, given good facilities and technical support and within a supportive accountability system.
2. The final-year extended project, the *profielwerkstuk* (section 4.6), is an excellent vehicle for encouraging independent practical research projects in science. Unlike the extended project qualification (EPQ) in England, it is compulsory for all students in their final year, encourages practical science to be done for those who have chosen a science profile, and is possible to undertake in partnership with another student. The introduction of an equivalent element into the curriculum for England would be transformational.
3. We heard about an interesting programme that offers funding to teachers (usually three or four years into their career) to do a school-based PhD. They spend 3 days teaching in school and two doing their research. The unit cost (paid by the government) is about 250,000 Euros. A small scheme of this kind might be created in the UK to look at an aspect of practical science, such as its assessment, and would have the advantage of building capacity as well as knowledge.

4. The 'golden rules' for good practical work are the same for schools in the Netherlands as they are in England. Teachers need to be clear about the purpose of the practical activity, linking it to theory learning wherever appropriate, and engaging students in dialogue before, during and after the activity to ensure that the intended learning has been achieved. We might usefully compare the ways in which English and Dutch science teachers gain these practices and whether it is external or internal factors which enable them to be implemented best.
5. We got the impression that Dutch teachers exercise much autonomy in their teaching methods, but often act in isolation from their colleagues. Can Dutch autonomy (for example, to choose and develop the experiments a teacher carries out) be married to the tradition of teamwork that is found in many English school science departments?
6. The active involvement of laboratory technicians in working with students in the lab not only helps teachers and students (particularly with their project work) but also acknowledges the often unique skills which technicians can bring to the processes of teaching and learning practical science. As more schools in England struggle to recruit and retain science teachers, time and money might be well spent on enabling technicians to take a more prominent role working with students.
7. The model for the assessment of practical skills in the school-leaving assessment – diverse, school-based and carried out by teachers and technicians – may be worth exploring further. In particular, we were interested in the use of the national exam to moderate teacher assessment. In none of the schools we visited did teachers or students report that assessment dominated their practice - a virtually unheard of scenario in schools in England. However, while the assessment system is generally considered robust in the Netherlands, we did hear that the government wanted to introduce greater rigour in some aspects. New regulation sets out that large differences between the results of school and national exams in some schools are unacceptable.
8. The schools we visited appeared very informal by English standards. Relations between teachers and pupils were relaxed, but students were expected to take a significant amount of responsibility for their own learning. This responsibility was built up over time across the whole school, perhaps driven by the need to prepare students for a large independent project. This whole school culture is conducive to good practical project work in science, and encourages independence, collaborative working, and creativity. Could more English schools benefit from such a culture and how could this be supported?

ANNEX I: SOURCES OF EVIDENCE

A. DESK RESEARCH.

Main sources (accessed November 2015)

www.en.wikipedia.org/wiki/Netherlands

www.nuffic.nl/en/library/education-system-the-netherlands.pdf#page=3&zoom=auto,-158,814

www.oecd.org/edu/school/OECD-Evaluation-Assessment-Review-Netherlands.pdf

www.ncee.org/programs-affiliates/center-on-international-education-benchmarking/top-performing-countries/netherlands-overview/netherlands-instructional-systems

www.onderwijsinspectie.nl/binaries/content/assets/publicaties/2015/08/the-state-of-education-in-the-netherlands-2013-2014.pdf

www.eacea.ec.europa.eu/education/eurydice/documents/thematic_reports/133en.pdf

www.onderwijsinspectie.nl/binaries/content/assets/Documents+algemeen/2012/netherlands-key-figures-2007-2011-ocw.pdf

www.oecd.org/edu/EDUCATION%20POLICY%20OUTLOOK_NETHERLANDS_EN%20.pdf

www.ingenious-science.eu/web/guest/Netherlands

B. A CONSULTATION SEMINAR ON 1 DECEMBER 2015 IN AMSTERDAM WITH TEACHER TRAINERS.

Participants

Patricia Kruit, Amsterdam University of Applied Sciences

Wouter Spaan, Amsterdam University of Applied Sciences

Ton Ellermeijer, Centre for Microcomputer Applications

Harrie Eijkelhof, University of Utrecht

Erik Joling, University of Amsterdam

Ed van den Berg, Amsterdam Free University

C. HALF DAY VISITS TO GENERAL SECONDARY SCHOOLS ON 1 AND 2 DECEMBER.

The Amsterdam Lyceum,

Valeriusplein 15, 1075 BJ Amsterdam. VWO; about 1,100 students.

Rector Drs Roel Schoonveld (also a chemistry teacher);

Vice-rector Drs Tjeerd Volbeda (biology/chemistry teacher and Head of Science)

We met the Rector, Vice-rector, two teachers and two year 6 (final-year) students.

Damstede School,

Amsterdam, Rode Kruisstraat 83 1025 KM Amsterdam. VWO and HAVO; about 1,100 students.

School contact Ton Reckman

We met three teachers, two technicians and seven students, a mixture of year 3 and year 6.

St Bonifatius College,

Utrecht, Burg. Fockema Andreaelaan 7, 3582 KA Utrecht. Catholic, VWO and HAVO; about 1,500 students.

School contact: Kees Hooyman, Head of Science

We met four teachers, three technicians and about 15 students. We observed a class doing projects (*profielwerkstuk*).

D. A VISIT TO JET-NET AND PLATFORM BETA TECHNIEK, SCHOOL-INDUSTRY BROKERING ORGANISATIONS IN THE HAGUE, ON 30 NOVEMBER 2015.

Jet-Net Director-designate: Sebastiaan Smit; Project Manager: Emilie de Vries Schultink

Platform Beta Techniek Director: Beatrice Boots

ANNEX 2: EDUCATION IN THE NETHERLANDS – A BRIEFING NOTE

ABOUT THE NETHERLANDS

The Netherlands has a population of 16.8 million (making it the 10th most populous in Europe), 84% of which live in urban areas. It is ranked highly in terms of child well-being and adult happiness. It has relatively low unemployment, high GDP per head (12th in the world), low income inequality and one of the best work-life balances. It is divided into 12 administrative regions (provinces).

THE DUTCH EDUCATION SYSTEM

The Netherlands has one of the OECD's most devolved education systems, with schools enjoying a high degree of autonomy grounded in the principle of "freedom of education", which gives the right to any natural or legal person to set up a school and to organise teaching. All schools receive public funding, provided that they meet the requirements for schools in their sector. Central government sets learning objectives and quality standards that apply to both public and private schools. The Inspectorate of Education monitors school quality and compliance with central rules and regulations. Both public and private institutions exist at all levels of the education system; the private institutions are in most cases based on religious or ideological principles.

This has caused significant ethnic segregation in some areas with ethnic minority pupils more likely to be in low-performing schools, and less likely to have attained an academic qualification than native Dutch pupils.

The Dutch education system consists of eight years of primary education after which pupils take an exam (*Citotoets*) to determine which type of secondary education is best for them. The test is multiple-choice and designed to measure aptitude, rather than content knowledge, in Dutch, math, comprehension skills, study skills and "world orientation" (which includes geography, biology and history). The results, together with their previous performance, interests and goals (and parental influence) are taken into account when a Primary school makes a Secondary school recommendation. This makes the Netherlands one of only five Western European countries which select at age 11/12.

There are three routes through secondary schooling, generally sharing a common two years at the start:

1. VWO (six years) prepares pupils for academic programmes in the 14 research-intensive universities (WO);
2. HAVO (five years) prepares pupils for professional in one of 42 technical or professional higher education institutions (HBO);
3. VMBO (four years) prepares pupils for continuing vocational education at a specialist training centre or vocational school (MBO).

Figure 1: The Dutch Education System

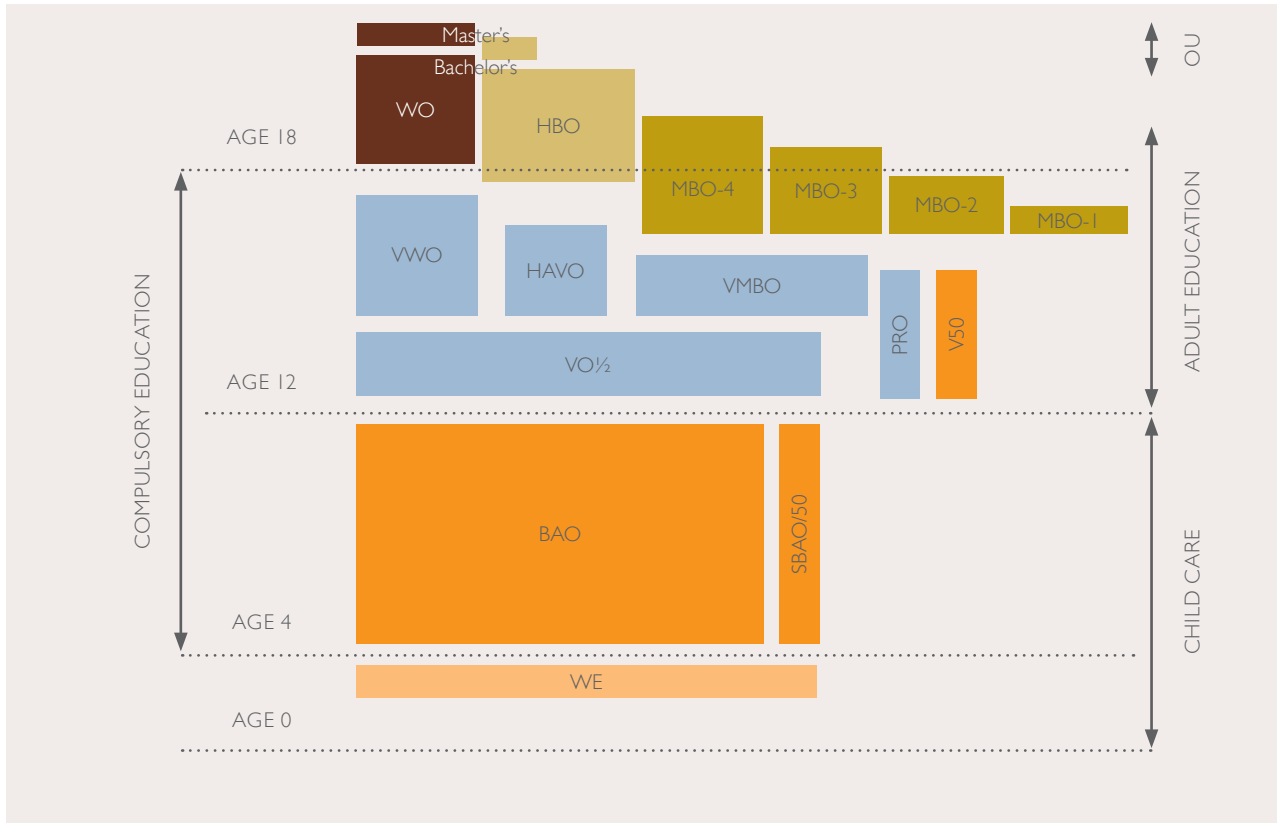
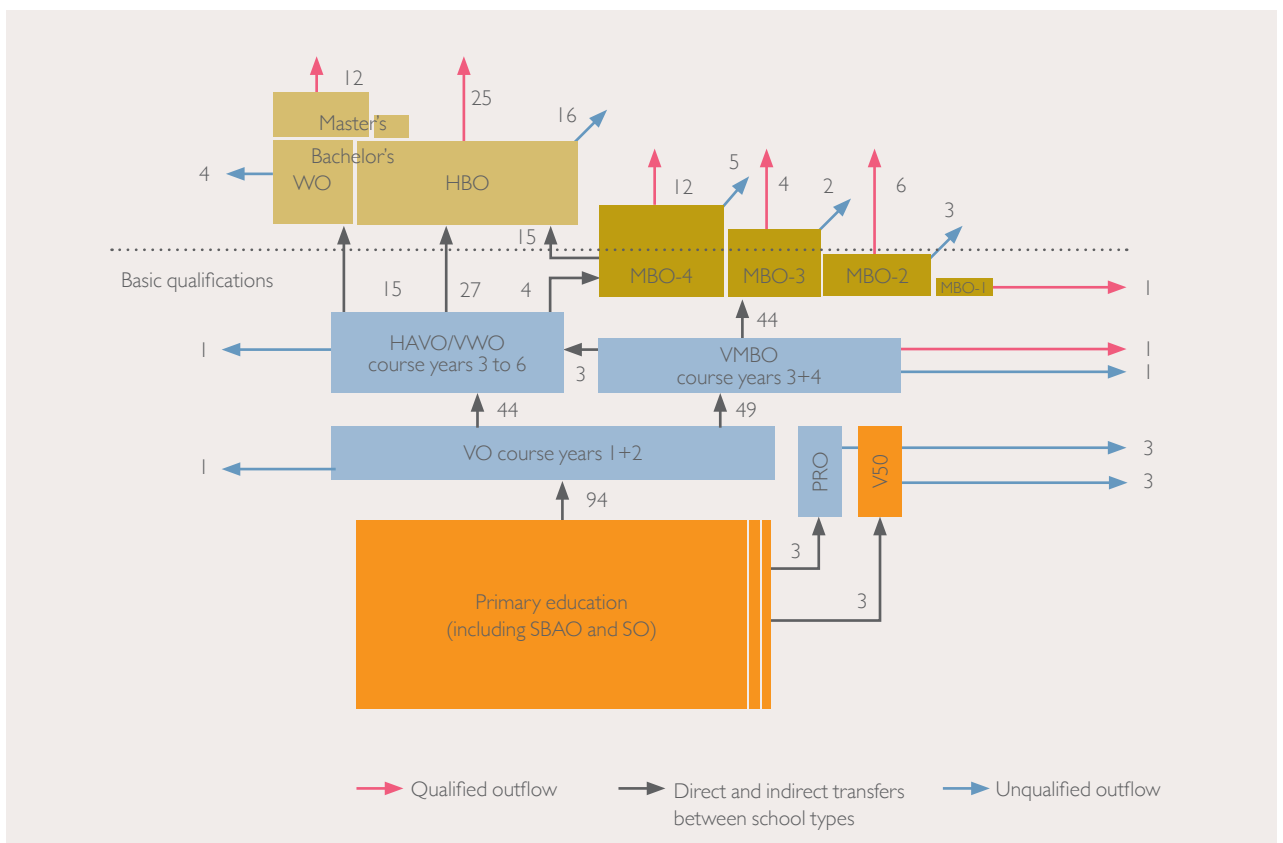


Figure 2: Movements in Dutch Education
In percentages of a cohort of pupils leaving primary education, 2012



CURRICULUM

The Dutch Ministry of Education, Culture and Science sets a general national curriculum framework. The framework outlines suggested time allocation and attainment targets (what students should know and be able to do) for subject areas and cross-curricular topics. However, schools are free to teach the core subjects in any way they see fit, provided they meet the attainment targets. The Ministry consults with the Education Council and the Consultative Committee for Primary and Secondary Education before establishing curriculum frameworks. Additionally, the government funds the National Institute for Curriculum Development, which serves as an advisory group to provide consultation on major education reforms and to guide and monitor curriculum implementation.

In the lower years of secondary school, all pupils follow a general curriculum. In the upper years of HAVO and VWO, pupils choose one of four subject combinations:

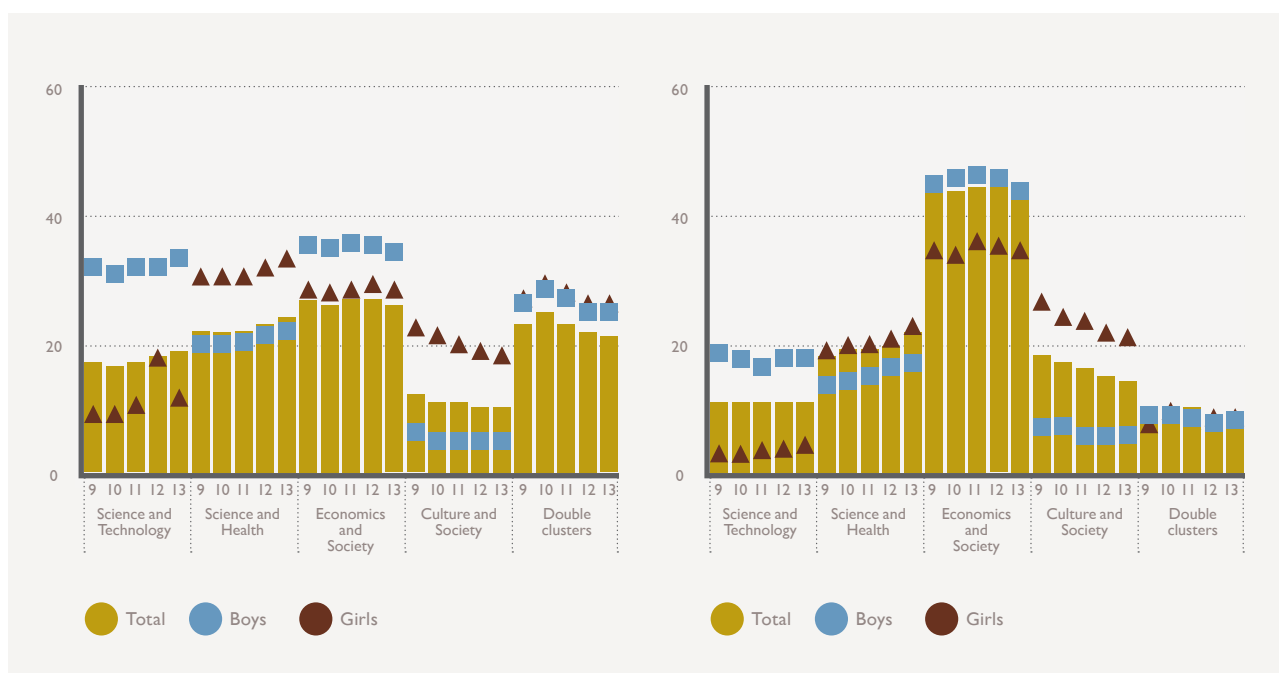
- Science and technology.
- Science and health.
- Economics and society.
- Culture and society.

Each subject combination includes a number of compulsory subjects: six for HAVO and seven for VWO. Besides their chosen specialised subjects, all HAVO and VWO students take a number of compulsory subjects or elements:

- Physical education and culture & the arts.
- A project relating to their specialised subjects, social studies (HAVO and VWO) and general science (only VWO, to be phased out before the 2015/2016 school year).
- Mathematics (all VWO pupils).

Figure 3: VWO students in the subject clusters
As a percentage of all VWO subjects in the subject clusters, course years 4, 5 and 6

Fig 4: HAVO students in the subject clusters
As a percentage of all HAVO subjects in the subject clusters, course years 4, 5 and 6



In the upper years of VMBO pupils choose an occupational sector with a view to further vocational education and training, and their future jobs. There are four sectors:

- Care and welfare.
- Engineering and technology.
- Business.
- Agriculture.

At the end of the second year, pupils also choose one of four learning pathways to suit their aptitudes and abilities. There are four options: theoretical, combined, middle-management vocational or basic vocational programme. It is also possible to specialise within a sector. For instance, the engineering and technology sector options include building techniques, metalworking and electrical engineering.

ASSESSMENT

The school-leaving examination for secondary education consists of a school examination and a national written examination at the end of the final school year.

School examinations are set by the school though the Ministry of Education, Culture and Science prescribes which subjects must be taught during the exam year. The school examination dates are not nationally fixed: schools are free to test pupils in particular subjects whenever they wish. The school exam usually comprises two or more tests per subject, which may be oral, practical or written. Subjects outside the national exam framework may be completed before the final year of school but must be completed and the results submitted to the Inspectorate before the national examinations start. The school examinations are produced by the schools themselves or by test institutes and are marked by the pupils' own teacher. There are also practical assignments for which no marks are given, only an acknowledgement that the examinee has completed them properly.

There is one national written exam per subject for all pupils receiving the same type of education. Whether a subject is compulsory or optional, the exam questions are the same across the whole country. The national exam always takes place at the end of the final year and is compiled by the Ministry of Education, Culture and Science. Pupils may sit exams in extra subjects, if they so wish and may ask for their extra subject results to be included in their list of grades, so that they count towards the overall result.

Starting in the 2015–2016 school year, secondary school pupils in the Netherlands will be given a distinction (“judicium cum laude”) on their school-leaving certificate if their average mark is 8/10 or higher. The measure applies to pupils in pre-university education (VWO), senior general secondary education (HAVO) and pre-vocational secondary education (VMBO). It will be a new way of acknowledging outstanding achievement by highly gifted and talented pupils.

All VMBO routes end in a national exam after which the VMBO diploma is awarded and students can progress to senior secondary vocational education (MBO) at a specialist training centre or vocational school. Those who took the theoretical route can also move into the academic pathway via the HAVO. Students in the MBO can choose a school-based route with full-time education including 20–60% of their time in employer-based training, or the apprenticeship route including more than 60% of their time in employer-based training. The majority (80%) choose the school-based route. For all MBO students, the responsibility of assessment and examinations is with their schools, which are legally obliged to involve the trainers in the process. MBO training programmes are offered in: engineering and technology; commerce and management; health care services; and agriculture.

SCIENCE EDUCATION IN THE NETHERLANDS

The country is already investing in a wide array of STEM-related initiatives, not least Jet-Net⁷ and Platform Beta Techniek.⁸ The latest manifestation of Netherlands planning capacity and forward thinking attitude is the Techniekpact – or Dutch Technology Pact 2020⁹ – a joint initiatives launched in May 2013 by the Government, regions, business community, trade unions and schools.

Jet-Net – Youth and Technology Network Netherlands (51) – was established in November 2002 as a partnership between Dutch industry, the government, and the education sector. Jet-Net was created in order to assist secondary schools to enhance the appeal of their curriculum and science teaching. Since 2008, the network has comprised thirty national and international companies, representatives of the ministries of Education and Economic Affairs, trade organisations and the national Science and Technology Platform. Almost a third of upper general secondary (HAVO) and pre-university (VWO) schools currently participate in the network.

⁷ www.ingenious-science.eu/web/guest/jet-net-10th-anniversary

⁸ www.pbt-netwerk.nl/home

⁹ www.investinholland.com/nfia_media/2015/05/Summary-Dutch-Technology-Pact-2020.pdf

The Platform Bèta Techniek has been commissioned by the government, education and business sectors to ensure sufficient availability of people who have a background in scientific or technical education. This approach has been formulated in the Deltaplan Bèta Techniek, a memorandum on preventing workforce shortages. The initial aim was to achieve a structural increase of 15 per cent more pupils and students in scientific and technical education. This target has been reached. The intention is not just to make careers in science more appealing, but also to introduce educational innovations that inspire and challenge young people.

The plan, therefore, targets schools, universities, businesses, ministries, municipalities, regions and economic sectors, while the objective is to ensure that the future supply of knowledge workers will meet future demand, and that talented professionals already in the job market are more effectively deployed. Particular attention is paid to girls/women and ethnic minorities. The strategy, started in 2004, was evaluated in 2010 and has a new timeframe lasting until 2016. The approach is divided into programme lines for primary and secondary education, vocational and higher education.

The Netherlands has also made efforts to improve the capacity of schools to improve through a three-year programme called Schools have the Initiative (School aan Zet, 2012). This programme aims to leverage internal motivation to increase the effectiveness of the education provided through work in six areas:

1. Results-oriented work.
2. Human resource management / learning organisation.
3. Basic skills.
4. Dealing with differences between students.
5. Excellence / gifted students.
6. Science and technology skills.

Participation in this programme is voluntary and begins with schools defining their own goals and ambitions.

With the help of experts to set objectives, schools can conduct three sessions known as ambition conversations as well as three evaluation conversations to monitor achievements in line with their own expectations. The programme also encourages schools to apply for funding to provide for, among other things, visits of independent experts and so-called critical friends to participate in these conversations.

The Dutch state still feels it has a way to go before it can be relaxed about the number of children studying STEM subjects and choosing STEM careers – particularly technology. “In the period to 2020, more than 70,000 construction workers, installers, electricians, metal workers, engineers and system analysts will be retiring each year. . . To be able to compete internationally and to take advantage of market opportunities, the Netherlands needs more highly skilled technologists.”

APPENDIX 3:
COUNTRY REPORT:
SINGAPORE



GATSBY

I EVIDENCE GATHERING

This report has been written by John Holman and Beth Jones and is based on the following sources. Further details of the sources are in Annex 1.

- A. Desk research.
- B. Visits to three secondary schools across Singapore: Tanjong Katong Secondary School (secondary 1–4) on Monday 29 February 2016; Raffles Institution (secondary 1–4 and junior college) on Tuesday 1 March; and Swiss Cottage Secondary School (secondary 1–4) on Wednesday 2 March.
- C. A visit to Bukit View Primary School on Thursday 3 March 2016.
- D. A visit to the Academy of Singapore Teachers (AST) to meet Master Teachers and officials from the science Sciences Branch of the Ministry of Education (MOE) on Tuesday 1 March.
- E. A meeting with science education academics and teacher trainers at the National Institute of Education (NIE), Nanyang Technological University (NTU) on Wednesday 2 March 2016.
- F. A visit to the Science Centre Singapore on Thursday 3 March.

The visits and meetings in Singapore were organised by Associate Professor Ramanathan Subramaniam of the National Institute of Education in Nanyang Technological University, Singapore. He also provided individual expert advice throughout the visit.

2 OUTLINE OF EDUCATION IN SINGAPORE

This is a summary; there is further detail in Annex 2.

Singapore is a city state, small in size, with a population of 3.9 million permanent residents and covering an area of 719km. It has the world's 5th largest GDP (when population size is taken into account). The ethnic background of the population is mainly Chinese, Malay and Indian.

The Ministry of Education (MOE) – the government agency with responsibility for schools and colleges – distributes funding, develops the national curriculum, and recruits teachers. It also organises professional development courses through the Association of Singapore Teachers (AST). The Singapore Assessment and Examinations Board (SEAB) develops and runs national leaving level examinations – at the Ordinary and Advanced level examination, it does so in collaboration with the University of Cambridge Local Examinations Syndicate in the United Kingdom.

Education is held in high regard across society. There is significant provision in selected schools to support gifted students through extension opportunities. The Ministry of Education supports this through Gifted Education Programmes and associated funding. Additional funding is available to schools with a specialism.

There are 154 secondary schools (for students aged 13–16) and approximately 30 post-secondary institutions (for students aged 17–18) in Singapore. Schools are organised into four zones; North, East, South and West. Within each of these zones, schools are grouped into 7 or 8 clusters. These zones and clusters provide the structure for both the accountability system (via a zonal superintendent) and professional development networks.

Government funding is available to all schools in Singapore, but additional funding from parents is required for autonomous and independent schools. Parents who are unable to afford the contributions can access funding via the government Edusave scheme or via bursary schemes available from these schools. This makes education available to all young people.

The MOE produces a national curriculum which is complemented by subject syllabuses. It includes learning outcomes relevant to subject content knowledge along with character and value statements. The Ministry also produces an Approved Textbook List (ATL) to guide school choice of support material. Students are required to pay for their own textbooks and workbooks.

Primary school is compulsory between the ages of 7 and 12. The vast majority of students (about 98%) go on to secondary education until the age of 16. Secondary school students follow one of four tracks; Special, Express, Normal (Academic) or Normal (Technical). Express students (about 30% of the cohort), after four years, generally tend to progress to junior college in preparation for university. Students on the Normal tracks will, after five years, tend to progress to polytechnics or junior colleges. It is possible to move between tracks.

There is a national exam at the end of primary school – the Primary Schools Leaving Exam (PSLE) – which determines the student’s destination for the next stage. Allocation of secondary school places is carried out by the MOE. Parents are asked to rank their preferred schools, and pupils with the highest PSLE scores are allocated their choice of school first. The popularity of a school can change over time and schools focus on how they can they can appeal to parents, as the most popular schools will have the most academically able students.

The school day is built up of academic lessons (typically 08.30–14.30), followed by an afternoon of Co-Curricular Activities (CCA). There is an expectation that all students take at least one CCA. Lunchtime activities are uncommon as the break is often very short. Teachers will all have responsibility for leading at least one CCA class, which may be unrelated to their subject area.

2.1 ACCOUNTABILITY AND ASSESSMENT

National external examinations occur at the end of primary school (PSLE), secondary school (O level, N level or NT level) and post-secondary education (A level or technical qualifications). National exams are administered by the SEAB. At each stage, these national exams determine a student’s access to the next stage of education. Schools and students place importance on these exams, and their structure affects classroom practice. Internally set school exams that track student progress are taken seriously in Singapore.

There is significant amount of trust within the Singapore education system. The MOE trusts school principals and, in turn, school principals trust teachers, and there is no overbearing accountability system. School inspections are decentralised and carried out by one of several superintendents, each working across a school zone. Inspections are focused on school structures rather than on the performance of individual teachers. There are no published league tables of academic results; they were abolished several years ago by the MOE because they were having a negative impact on the school system. The top schools are identified and organised into five tiers. These top ‘elite’ schools are given greater freedoms by the MOE.

Schools are managed by an advisory committee, which includes parents, key stakeholders and alumni.

The relationship between the MOE and schools is positive, with staff within the MOE being predominantly drawn from the teaching profession. The transition from classroom teaching to policy is facilitated by clearly identified career pathways. Curriculum development involves not only MOE staff but also subject specialists and teachers.

The national assessment system for science is under reform, specifically the approach to practical science assessment (see section 4.7).

3 SCIENCE EDUCATION IN SINGAPORE

3.1 SCIENCE IN THE SCHOOL CURRICULUM

The science curriculum documents place inquiry at the core of the syllabus, but the enacted curriculum is focused on knowledge statements and specific skills. The MOE is reflecting on how to make the science curriculum more contextual, they have worked with the Science Centre Singapore to implement a STEM Applied Learning Programme (see section 4.1).

In lower secondary school (grades 7-8), science is taught as ‘general science’, a combination of biology, chemistry and physics. In upper secondary (grades 9-10) the way in which science is studied is influenced by the student’s pathway. For example, students taking the Express route are required to take chemistry (O level) and then one other science subject from biology or physics. We found the most common combination was chemistry and physics. Some students also choose all three sciences. Students on the Normal (academic) pathway study combined science, made up of two science subjects.

3.2 SCIENCE TEACHERS

Student Teacher training is organised by the MOE but done at the NIE. Schools provide the MOE with details of upcoming vacancies and the MOE looks to recruit new trainees based on these numbers. Teaching is a highly prestigious profession with starting salaries higher than doctors. Applications for training places can have a ratio of 40:1 in desirable subjects. A head of department can earn \$9,000 a month (£4,600) after a few years.

Student teachers are salaried during their training, but are required to pay back fees along with compensation if they leave or fail during training or their first years of teaching (an amount which can be in excess of \$60,000, or £31,000). There is therefore a strong incentive to commit to the profession. To ensure that the best candidates enter the profession, applicants often spend 3–9 months in a school on an 'untrained teacher contract'. At the end of this period, the school recommends whether the applicant should be accepted into the teacher training course. This also gives potential teachers the chance to experience the profession before committing to the training.

The majority of teachers follow a graduate pathway, taking a bachelor's degree at university followed by a post graduate diploma in education (PGDE). The PGDE is about to be extended from 12 months to 16 months, in response to teachers and schools wanting a longer preparation time. This additional time will cover areas that schools identified as issues eg parental engagement.

There are three tracks through teacher training: junior college track, secondary track, and the primary track. Teachers trained on the junior college track can also teach in secondary schools. The secondary and primary tracks are restricted to their chosen institution type. In addition to core teaching practices and educational studies, trainees on any of the tracks choose two curriculum study areas; a major (CSI) and a minor (CS2). Physics, chemistry and biology are treated as different curriculum study areas. Teachers will also have to undertake a teaching placement – practicum – as part of their programme. Teachers therefore have a dual specialism and teach both their major and minor subjects. As science is taught as 'general science' (a combination of the three sciences) in lower secondary, teachers will be teaching outside of their specialism some of the time.

Newly qualified teachers have a 25% reduction to their teaching timetable compared to experienced teachers. The new teacher will also be paired with an in-school mentor during their first years. Mentors also have a 15% reduction to their teaching timetable to support new teachers.

Professional development is highly structured and valued. A newly trained teacher is viewed as someone on the beginning of their journey to becoming a teacher. The Academy of Singapore Teachers (AST), part of the MOE, organises and coordinates professional development programmes. They organise compulsory professional development (relating to statutory changes to curriculum and assessment), networking meetings and conferences, and a programme of courses - most of which run over several days – designed with input from practising teachers. There are three clearly defined professional pathways: Teaching (leading up to Master Teachers), Leadership (leading up to Directorship at the MOE) and Specialist (leading to Specialist in a subject area). Teachers have the autonomy to choose the track they wish to pursue and seldom move between tracks during their career. Progress is not automatic: teachers must undertake professional development and apply for positions at the next level on the ladder. Besides AST, the NIE also conducts professional development programmes for teachers.

As the country has a relatively small number of secondary schools (154) the AST is able to track whether schools are attending professional development courses. We heard that there are approximately 1,000 physics teachers in Singapore and they all belong to the national physics teacher subject cluster. The AST therefore has a relationship with all of these teachers and can (relatively) easily detect if some schools are not attending events and encourage them to engage.

Teachers are entitled to 100 hours of professional development per year. This includes internal development meetings. The majority of schools have a Staff Development Officer who ensures teachers to have a learning plan, organises professional development and keeps records of activity. Teachers have the autonomy to choose their own professional development. It is not difficult for teachers to take up professional development as they have a timetabled space each week for this type of activity.

Schools encourage (or require) their staff to be members of school learning teams and communities, which meet once or twice a week with colleagues to work on subject specific or school wide developments. This is additional to short team meetings to address administrative matters.

3.3 SCIENCE BEYOND THE CURRICULUM

Science Centre Singapore creates science engagement opportunities for young people across Singapore. Over 90% of primary and secondary schools take part in programmes organised by the Science Centre, and all trainee science teachers from the National Institute of Education (NIE) attend the centre during training. In addition to an exhibition that can be accessed by members of the public, the majority of school activities and programmes take place in private spaces within the science centre. Schemes that support practical science include:

- The Club House: a youth club scheme with 200 members. Participation is by self-selection and members join for five years. The club house space is only accessible to members, and activities and projects are decided upon by the membership. Membership costs \$20–50 per month.
- Cradle: a project space with engineering equipment to facilitate student led projects. Schools can also book onto specific courses through this programme across a number of themes, which include physical sciences, engineering, research and prototyping fabrication. They also organise project based work experience and teacher professional development.
- STEM Applied Learning course: an in-school programme run by the centre's STEM Inc team. The centre developed enquiry led curriculum modules set in various contexts (eg water quality or sustainable energy). Aimed at lower secondary, schools can choose to do one or more modules. Industry partnerships are also brokered with schools to help provide support and context for the programme.

Timetabled Co-Curricular Activities (CCA) provides a formalised opportunity for students to access extra-curricular STEM activities. All the schools we visited provided STEM related opportunities that were either practical or project based. For example, robotics clubs, environment clubs and preparation for national science fairs.

4 RELEVANT FINDINGS

4.1 TYPES OF PRACTICAL SCIENCE

Singapore class sizes are relatively high: nationally there are an average of 34 students per class, and we observed the practical work being taught in groups of 40, or split into two groups of approximately 20 when practising for examinations. Practical sessions were always timetabled into large laboratories and we were told that some have capacity for 50. Practical classes were often supported by 'allied educators', an equivalent role to teaching assistants in the UK. Students were well behaved, and lessons were meticulously planned, all of which enabled practical work to take place in large groups.

In both upper and lower secondary, practical work was often used by teachers to support theory, to introduce a new area of study or to reinforce a previous topic. For students on the Express route, practical work in upper secondary was more frequently used as preparation for O level assessments.

Demonstrations play an important role in the Singaporean classroom. Teachers value their use; they do not replace hands-on practical work but are used as a tool to introduce a topic or carry out an experiment that would otherwise be too dangerous for students.

The STEM Applied Learning Programme led by the Science Centre Singapore has given schools the chance to reconceptualise how they use practical work in a more integrated, enquiry led and contextualised way. In one lesson we saw a class of 40 students in their first year of secondary school taking part on this programme. Working in groups of four they observed and discussed the sublimation of solid carbon dioxide (dry ice). Students were trusted to use gloves to handle the solid carbon dioxide, and discussion was lively and focused. We heard that many schools were embracing this new approach. This lesson also highlighted the mature approach to health and safety that exists across schools. The MOE provides guidance on use of chemicals, technicians ensure this guidance is followed and teachers communicate the importance of health and safety to students. We heard from several teachers that giving students the opportunity to manage risk within practical work was an important part of their education.

We did not see any evidence of extended investigations or authentic research forming part of the core science curriculum. These opportunities did exist in abundance, and were of high quality, but as they were extension opportunities for students with aptitude for, and interest in, science (see section 4.6).

Technology was not as widely integrated into teaching, which was somewhat surprising given that Singapore is a tech-driven society. Schools did have access to data loggers, and some class sets of tablets, but they did not seem to be used frequently. We also saw some impressive pieces of science and engineering equipment in both schools and the Science Centre Singapore but its use was targeted for specific projects and not used as part of the core curriculum (see section 4.6). The MOE have been trying to increase the use of technology and have recently supported a project involving small sensory devices carried by students that track their movements and air quality during the day. We saw the project being embraced in Bukit Primary School. The data from students across Singapore is then made available to schools to analyse, a similar approach to 'citizen science' in the UK.

Most schools were comfortable using their own environment and eco-gardens to teach some aspects of biology but fieldwork beyond the school grounds was rare.

New experiments are introduced into to schemes of work when teachers share ideas within school departments, when courses have been attended (although specific practical courses did not seem to be frequent) or through the online resource sharing portal, OPAL (One Portal All Learners) funded and hosted by the AST. We heard that this was preferentially used over conventional search engines when looking for resources. It hosts resources shared by teachers across all subject disciplines and we were told that reassurance that another teacher was recommending, or had used, the resource made the portal favourable.

4.2 HOW FREQUENTLY?

Practical work was carried out in a fairly consistent amount across the schools visited, with all classes in lower secondary, upper secondary and junior college carrying out practical work every week. Although difficult to generalise due to differences between schools, teachers and subjects, we were told approximately 25% of a student's time studying science involved practical work. Lab time was timetabled into schedules over double or triple periods during the week, so lab sessions would last between 60 and 90 minutes. Some teachers also choose to integrate demonstrations and some hands-on learning into their non-laboratory classroom theory lessons, but this did not seem to be common.

In junior college, practical work always takes place in allocated laboratory sessions. Science students will spend time in the laboratory, in lectures (sometimes in large numbers in a university-style lecture theatre) and attending small group tutorials.

4.3 ATTITUDES TO PRACTICAL SCIENCE

Both the MOE and practising teachers articulated a wide variety of purposes for practical work. We observed teachers deploying it in a variety of ways and, although assessment is a clear driver for the approach taken in practical classes (especially for those students close to taking national examinations), teachers did not talk at length about assessment driving their behaviour.

The MOE believes that it is not possible to teach science without practical work, it is marbled through the discipline. There was a sense that the entire profession – from individual teachers to the MOE – held a strong belief that practical work was important. Practical work was therefore not seen as under threat, and effort was focused on how to improve its use.

We were told of the many benefits of practical work from government officials and teachers including: understanding of risk, modelling complex ideas, and developing technical and inquiry skills. We also heard that it was the unpredictability of live experiments that ensured their place in the classroom, as this was something that could not be replicated in simulations.

Teachers take responsibility for ensuring they are appropriately skilled to deliver practical work (see section 4.8). From the moment they arrive in the classroom, teachers are expected to carry out the same volume of practical work as more experienced teachers. We were told that, over time, it is not the *amount* of practical but its *use* that changed; it becomes more integrated and focused.

4.4 FACILITIES AND FUNDING

Laboratories are reserved for practical lessons, and classrooms are used to teach theory. Laboratories were designated to specific science disciplines. Laboratory provision was thought to be sufficient by the teachers we met. Teachers did not always teach in the same laboratory as they often taught more than one science discipline (particularly in general science in lower secondary). Laboratories were well serviced with gas, electricity and water. Arrangements of benches varied (rows or hubs) but service points were commonly placed throughout rather than around the edge of the room.

Preparation rooms were adjoined to laboratories and schools we visited had dedicated prep rooms for biology, chemistry and physics. Prep rooms and classrooms were similar in size, or larger, than those found in the average UK school. Prep rooms had storage for hazardous chemicals and were equipped with fume cupboards. However, not every laboratory had a fume cupboard.

Equipment was similar to that which you would find in the UK. It was stored in preparation rooms, in secure storage areas or in classrooms. Equipment was clean, well organised and well maintained. Safety equipment such as lab coats and eye protection were similarly well maintained and students were using it appropriately in lessons.

Text books are used widely by schools to support practical work, and publishers produce teacher guides, student theory workbooks and student practical workbooks. These practical workbooks provide outlines of experiments and spaces for students to record results and answer questions about practical work. Students pay for their own set of text books and workbooks.

Funding was not considered a barrier to practical work: departments reported being appropriately funded and budgets did not restrict the types of activities that could be carried out. At the start of each academic year teachers and technicians compile lists of all the required equipment and consumables they anticipate needing for the year. This list is then entered onto the national school procurement system – GeBIZ – and science suppliers bid for the contract to provide this equipment. When the contract is awarded, schools then order the equipment throughout the year from this company. For smaller unanticipated purchases (under \$3,000, £1,500) throughout the year, this process does not have to be repeated. This process was not deemed to be over bureaucratic as it ensured value for money and restricted the decision on which supplier to use to one point in the year.

Additional funding can also be sought from senior leadership for specialist projects, particularly those that align to any school specialisms. Additional funding is also available to support extension programmes for high achieving students from the MOE.

4.5 TECHNICAL SUPPORT

Singapore is resourced with a similar level of technical support to the UK, with 2–6 technical staff supporting science departments depending on their size. There are two types of technical staff, each with distinct roles; lab technicians and lab attendants. The lab technician maintains equipment, organises systems, orders stock, trials experiments and works with new teachers to set up practical work. The lab attendant is the more junior role and they support lab technicians, focus on delivering equipment to classrooms, washing up and organising equipment. Neither type of technician spends time working with students in class. Technicians we spoke to had trained through a technical pathway, often studying at a polytechnic. We were told that schools do not have any trouble recruiting technical staff.

Before a practical class, teachers request the equipment they need from technicians, often a few days in advance of the lesson. The technicians will prepare and test the equipment and deliver it to the appropriate lab. They will often set up group, or individual, sets of equipment for students. Technicians will then clear and put it away. Students did not seem to have a role in selecting or cleaning equipment.

Although technicians do not attend departmental meetings, they do have the opportunity to undertake professional development, for example, we were told of a scheme which gave technicians the opportunity to spend time in industry to update their skills. The AST also supports technicians by organising technician networks in each zone.

4.6 PROJECT WORK

Investigations and long term projects are not central to academic curricula and examinations in Singapore. However, extension opportunities and associated facilities are available to students with significant interest and ability in science, though they are not accessed by all students.

The research and project spaces we saw in Raffles Institution were world class. Several project spaces, including their 'open lab' and 'cluster lab', were available for use across the secondary school and junior college. They are staffed by full-time technicians and 'researchers in residence' (with PhD qualifications) who are employed by the school. Students are encouraged to use the spaces independently to initiate projects, have discussions with the researchers and read academic literature. The majority of students who carry out projects in these spaces (approximately 50 students per year in the open laboratory) do so at the end of the academic year and into the summer holidays. Students can also contribute to data collection relating to longer term projects in the lab. The aim of the lab and project spaces is to extend those with significant interest in science, approximately five percent of the student population, and create opportunities for excellence (often in national or international science or engineering competitions) and even scientific publications. There is also a month long teacher placement scheme in which staff can work on a project with the researchers in residence to develop their own research skills.

These project labs at Raffles Institution contained advanced facilities including powerful computers, 3D printers, clean rooms, atomic emission and other spectrometers, and advanced centrifuges. Funding for this activity was supported by MOE, and also by industry and past alumni.

We also saw this type of creative project space in the Cradle lab in the Science Centre Singapore. They were able to support individual engineering projects and provide access and training on pieces of specific technical equipment.

4.7 ASSESSMENT OF PRACTICAL SCIENCE

Practical assessments contribute about 20% towards the final grade of O level and A level qualifications. In both of these examinations the practical assessment is undergoing a period of reform from internal to external assessment. The current assessment approach is called the School-based Practical Assessment (SPA) and involves teachers administering a series of three practical assessments over the course. The approach is very similar to the UK controlled assessment. The experiments that form the core of these assessments are decided by the MOE. The first two assessments (worth 36 marks) assess the collection, analysis and processing of data. The final assessment is focused on planning (worth 24 marks). Teachers would mark the scripts (including questions about the experiment and results tables) produced by students and provide a sample to the MOE for moderation. There is no direct observation of a student's skill at carrying out practical work. Schools carry out internal moderation to ensure consistency of grades. Students also keep a record of all of their practical work leading up to and including the assessments. These portfolios can be spot-checked by the MOE.

The MOE is now in the process of implementing a new terminal, externally assessed, practical exam. The impetus for change came from the narrowing of practical work that teachers were reporting. The ongoing internal assessment was driving teachers to focus their practical work on drilling students for the SPA. Interestingly, the N (academic) levels have always had a terminal practical exam and the MOE saw that practical experiences were not so narrow when this approach was used. A levels are already changing, with 2016 being the final year of the SPA. O levels are changing in September 2017. Teachers reported feeling positive about the changes, though a little concerned about the length of the exam.

School assessments used to track student progress are seen as important as national exams by both teachers and students. These assessments are designed by schools and can involve practical elements, but the approach taken varied between schools.

Schools with increased freedoms from the MOE (autonomous and independent schools), such as Raffles Institution can offer a wider range of programmes as well as Integrated Programmes (IP). With their cohort of able students, they have removed the age 16 examination point (O levels): as all of their students continue with Raffles Institution for their IB or into Raffles Junior College for A level examinations at age 18. They use internal assessments to measure progress but the removal of the O levels has given them greater flexibility in the curriculum in the lower year groups.

4.8 TEACHERS' TRAINING AND CPD

Science teachers are trained in two out of the three science curriculum subject areas (biology, chemistry and physics). It is possible to train in two unrelated curriculum areas but this is rare. There did not appear to be any recruitment or retention problems within the sciences. School science departments therefore have specialist teachers in all science subjects. Interestingly about half of the physics teachers have studied engineering.

Given the rigorous selection process for entering teaching (see section 3.2), science teachers begin their training with a good quality science degree in one science discipline. Although practical skills are not taken into consideration when interviewing and reviewing applications for teacher training places, it is assumed that teachers arrive with a high practical skills level developed during their degree. School and college curriculum content and practicals are covered during the training, but not comprehensively.

This is not seen as a problem as practical skills can be further developed on arrival into a teacher's first position. This is facilitated by a school mentor, other teachers in the department and technicians. Teachers at any stage of their career are also encouraged to observe colleagues' lessons. We heard examples of class observations occurring as frequently as once a week. All teachers said that they practiced experiments before they used them in class; newer teachers would practice more frequently than experienced teachers who only practiced when introducing new experiments. Teachers can continuously update their skills through courses run by the AST.

The AST runs some courses which are focused on practical skills; however, current courses relating to practical work were focused on changes to practical assessment. The feedback loop from science teachers into the AST appeared to be very coherent. Therefore, if a need was identified by teachers, professional development would be provided.

There is a strong sense of team spirit, fostered by the AST, across science departments and more widely across the profession in Singapore. Teachers want to improve and want their colleagues to improve too. There is an understanding that it takes time to become an excellent science teacher.

5 EMERGING LESSONS FOR ENGLAND

1. The teaching profession in Singapore is impressively structured. Teachers undergo a rigorous recruitment process which results in committed professionals. The career structure provides clear progression tracks which recognise and reward both leadership and subject expertise. Ongoing professional development is held in high regard and has a strong feedback loop to teachers which ensures that what is offered is what is wanted. Professional development includes quite simple 'tips for teachers' which might be derived by some but are what can cumulatively make a difference.
2. The AST creates a strong sense of team spirit among teachers, with sharing good practice being at the heart of their professional development. Science teachers are supported and celebrated as they become more experienced. (A possible model for a College of Teaching?) This all leads to a science teacher workforce which is stable and skilled, enabling frequent practical work to take place.
3. Teachers in Singapore have access to good technical support through both lab technicians and lab attendants. Could nationally consistent job descriptions for technicians in the UK result in even more efficient technical teams and a clearer understanding of the scope of their role?
4. A centralised procurement process for science equipment at the start of the academic year ensures value for money and reduces time spent looking for the 'best deal' during term time. In the UK, local authorities previously brokered this type of purchasing through CLEAPSS, but could a centralised system be possible within the current school landscape through Academy chains, Local Enterprise Partnerships or the National STEM Centre?
5. The research programmes and project spaces in Raffles Institution were world class. Supported by full-time researchers and technical staff, they provide students with an opportunity for supported and self-led investigative work. Although focused on the most able and dedicated students in Singapore, could such schemes be replicated for all students across the UK?
6. Singapore had a mature and appropriate attitude to health and safety. Risk and safety precautions were taken seriously (protective equipment was available and chemicals were stored correctly), but risk was not removed from all experiments. Confident specialist teachers coupled with the good behaviour of students meant that learning about risk could be part of the practical experience.
7. The MOE is wrestling with the tension between assessing a student's ability in science without distorting how it is taught. They, like the UK, have moved away from a controlled assessment style model (the SPA) but have chosen to move towards a terminal, externally assessed practical exam, keeping practical work contributing 20% towards a student's qualification.
8. The Singapore education system is built on a foundation of trust and professionalism. The MOE, school principals and teachers all feel being part of the same community, with little animosity existing between these groups. Everyone is reflective and focused on improvement. This could, in part, be due to the lack of any overbearing accountability system.
9. The curriculum is content-focused, but this does not militate against good practical work, which is possible regardless of curriculum content.
10. Teachers are extremely well organised in practical work. They know exactly what they plan to do and arrangements are meticulous. This enables the teacher to focus on developing individual students' skills.
11. Demonstrations are highly valued and often used to introduce a class practical.

ANNEX I: SOURCES OF EVIDENCE

A DESK RESEARCH.

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www.straitstimes.com/singapore/education/jc-v-poly-the-pros-and-cons

www.en.wikipedia.org/wiki/Academic_grading_in_Singapore#Junior_college_level_28GCE_A_and_AO_levels.29

www.en.wikipedia.org/wiki/Education_in_Singapore

www.en.wikipedia.org/wiki/Institute_of_technology#Singapore

[www.en.wikipedia.org/wiki/Junior_college_\(Singapore\)](http://www.en.wikipedia.org/wiki/Junior_college_(Singapore))

[www.en.wikipedia.org/wiki/School-based_Science_Practical_Assessment_\(SPA\)_for_GCE_%27O%27_Level_in_Singapore](http://www.en.wikipedia.org/wiki/School-based_Science_Practical_Assessment_(SPA)_for_GCE_%27O%27_Level_in_Singapore)

www.en.wikipedia.org/wiki/Secondary_education_in_Singapore

www.cia.gov/library/publications/the-world-factbook/rankorder/2004rank.html

www.moe.gov.sg/about#sthash.U2umlzIP.dpuf

www.moe.gov.sg/docs/default-source/document/education/syllabuses/sciences/files/science-primary-2014.pdf

www.moe.gov.sg/docs/default-source/document/publications/education-statistics-digest/esd-2015.pdf

www.moe.gov.sg/education/education-system

www.moe.gov.sg/education/secondary

B. HALF DAY VISITS TO SECONDARY SCHOOLS ON 29 FEBRUARY, 1 MARCH AND 2 MARCH 2016.

Tanjong Katong Secondary School, 130 Haig Road, Singapore, 438796.

Secondary 1–4 (age 13–16). Express students only (studying for O levels). 66% go onto junior college to study A levels, 33% go onto study at polytechnic. Centre for Excellence for design education and CCA (co-curricular activities).

School contact: Principal, Mdm Haslinda Zamani

We met the Principal, Deputy Principal, the Head of Science and five other science teachers across all three disciplines at a round table meeting. We toured the school and spoke with a school science technician.

Raffles Institution, secondary school and junior college, 1 Raffles Institution Ln, Singapore, 575954.

Express students only, no O levels taken, only A levels at end of junior college. Approximately 4,000 students.

School contact: Ms Imelda Chang, Head of Alliances

We met with the Head of the Alliances, Imelda Chang and the Deputy Principal for a roundtable discussion with the Head of Science and three other science teachers. We toured both the junior college and secondary school facilities including both the Open lab and Cluster lab, and observed and spoke to students in three practical lessons (a junior college chemistry lesson, and secondary level chemistry and biology lessons).

Swiss Cottage Secondary School, 3 Batock street 34, Singapore, 65637173.

Secondary school only, level 1–4, Express (60% students), Normal Academic (30% of students) and Normal Technical (10% of students). About 1,280 students.

School contact: Heng Yew Seng School Principal

We met with the Science Department Head, the Chemistry Head and the School Principal, observed three science lessons and spoke with a number of teachers during a tour of the school.

Bukit View Primary School on Thursday 3 March 2016.

1,168 pupils and 100 staff (76 teachers).

We met with Mr Koor Siew Hwa (Academic Vice-Principal) and Mrs Irene Kwek (Administration Vice-Principal) and the teacher responsible for science, and toured the science facilities available in the school.

C. A VISIT TO THE ACADEMY OF SINGAPORE TEACHERS (AST) TO MEET WITH MASTER TEACHERS AND OFFICIALS FROM THE MINISTRY OF EDUCATION (MOE) ON TUESDAY 1 MARCH 2016.

We had a round table discussion with 15 staff including master teachers and subject specialists and curriculum developers from the science division of the MOE.

D. A MEETING WITH SCIENCE EDUCATION ACADEMICS AND TEACHER TRAINERS AT THE NATIONAL INSTITUTE OF EDUCATION (NIE), NANYANG TECHNOLOGICAL UNIVERSITY (NTU) IN WEDNESDAY 2 MARCH 2016.

A meeting with Associate Professor Ramanathan Subramaniam and Dr Timothy Tan.

E. A VISIT TO THE SCIENCE CENTRE SINGAPORE ON THURSDAY 3 MARCH.

We met with the Chief Executive and directors of the Science Centre, toured the educational spaces and spoke with technical staff supporting the Cradle programme.

Lim Tit Meng, Chief Executive

Dr Andrew D Giger, Director of Strategy

Mrs Anne Dhanaraj, Senior Director of Education and Outreach

ANNEX 2: EDUCATION IN SINGAPORE – A BRIEFING NOTE

ABOUT SINGAPORE

Singapore is a city-state (a sovereign state consisting of a city and its surrounding dependencies). It has a population of 5.53 million, with 3.9 million permanent residents.¹ In 2015 it had a GDP of 294 billion USD, the 37th largest in the world,² and fifth in the world when population size is taken into account.³ The ethnic composition of the population is; Chinese (74.2%), Malay (13.3%) and Indian (9.2%).

Unemployment rates are around 2% of the adult population. 96% of the population is literate (a rise from 89% in 1990).⁴

EDUCATION IN SINGAPORE ⁵

The Ministry Of Education (MOE) develops and implements education policy in Singapore. It has control of the Government and Government-aided primary schools, secondary schools, junior colleges, and a centralised institute. It also registers private schools.⁶

An overview of the pathways through the Singapore education system can be found in Annex 3. It is compulsory for students to attend primary and secondary school.

The school year is divided into two semesters. The first begins in January and ends in May; the second begins in July and ends in November.⁷

¹ Department of Statistics, Singapore. 2015 statistics. www.singstat.gov.sg/statistics/browse-by-theme/population-and-population-structure

² World GDP ratings, 2015 data accessed from Knoema.com www.knoema.com/nwnfkne/world-gdp-ranking-2015-data-and-charts

³ United States Central Intelligence Agency, 'world factbook' www.cia.gov/library/publications/the-world-factbook/rankorder/2004rank.html

⁴ Department of Statistics www.singstat.gov.sg/statistics/latest-data#20

⁵ Ministry of Education, Singapore, Education Statistics www.moe.gov.sg/docs/default-source/document/publications/education-statistics-digest/esd-2015.pdf

⁶ Ministry of Education, Singapore www.moe.gov.sg/about#sthash.U2umlzIP.dpuf

⁷ www.en.wikipedia.org/wiki/Education_in_Singapore

| | Level/Grade | Typical age |
|---|---|----------------------------|
| | Preschool | |
| | Pre-school playgroup | 3–4 |
| | Kindergarten | 4–6 |
| | Primary school (Children enter P1 in the year they turn 7). | |
| | Primary 1 | 6–7 |
| | Primary 2 | 7–8 |
| | Primary 3 | 8–9 |
| | Primary 4 | 9–10 |
| | Primary 5 | 10–11 |
| | Primary 6 | 11–12 |
| | Secondary school | |
| Integrated institutions (offer secondary and post secondary combined) | Secondary 1 | 12–13 |
| | Secondary 2 | 13–14 |
| | Secondary 3 | 14–15 |
| | Secondary 4 | 15–16 |
| | Post-secondary education | |
| | Junior college | 16–18/19 (2 years/3 years) |
| | Polytechnics | |

There are 185 primary schools and 154 secondary schools in Singapore (including government funded and independent schools), with 234,499 pupils enrolled at primary school and 170,410 pupils enrolled in secondary school in 2014. In primary schools the average class size is 32, and in secondary it is 34, although this varies during the secondary years, peaking at the second year of secondary (average 36 pupils) and at its lowest in the fifth year (25 pupils).⁸

⁸ Ministry of Education, Singapore www.moe.gov.sg/docs/default-source/document/publications/education-statistics-digest/esd-2015.pdf

TEACHERS⁹

Teachers must complete a post-graduate qualification in teaching (based at a university) to enter the teaching profession. Teaching is a prestigious career and recruits the top graduates. There is a rigorous application process (including interviews and a proficiency test) to begin training. During their career, teachers are rewarded with performance-related bonuses.

The National Institute of Education (NIE) is the sole teacher training institution in Singapore. It is also the guardian of a formalised leadership career ladder for teachers. There are clearly defined professional development tracks, each with 13 stages that teachers are aware of and follow throughout their career.

There are three tracks:

- Teaching track – where teachers work towards becoming a Principle Master Teacher
- Leadership track – in addition to school leadership position, this track ultimately could lead to the position of Director General of Education in the MOE
- Specialist track – focused on research and policy; teachers could eventually become a Chief Specialist

Promotion between each level on the track is not automatic (although the first three years of teaching does result in pay rises for all staff), but teachers must be interviewed for positions at the next level. Although teachers may follow a single track (determined at the end of their first years of teaching), they can move laterally between them if their expertise and interests change.

PRIMARY EDUCATION

At the end of Primary 6 (age 11–12), the national Primary School Leaving Examination (PSLE) is held. The examination determines whether the student is ready to leave primary school. Places in secondary schools are allocated according to students' performance in the examination.¹⁰ In 2014, 97.9% of students passed the PSLE.¹¹

SECONDARY EDUCATION¹²

Secondary education in Singapore is based on four different tracks or streams:

- **Express Course (60% students)**¹³. For the most academically able. A four-year course leading to the Cambridge General Certificate of Education (GCE) O level exam. Students study English and Mother Tongue (MT) languages¹⁴ as well as maths, sciences and humanities. Students typically study at least 6 O levels.
- **Normal (Academic) (N(A)) (25% of students)**.¹⁵ A four-year course leading to GCE N(A)¹⁶ level exam. Subjects studied are similar to the Express course. Those who do well at the N(A) level can qualify to study for a further year to study for an O level, or go onto study a higher qualification at an Institute of Technical Education (ITE). Some students may sit some O level exams in subjects in their 4th year, and others may skip the N level and study O levels in their 5th year (like express students). There are two pathways (introduced in 2013) to polytechnics for N(A) level students;
 - A one-year Polytechnic Foundation programme (PFP)
 - A two-year Direct-Entry-Scheme to Polytechnic Programme (DPP)
- **Normal (Technical) (N(t)) (15% of students)**.¹⁷ A four-year course leading to the GCE N(T) level exam. Students learn English and MT languages, maths and subjects with practical or technical emphasis. Schools also offer Elective Modules eg nursing, hospitality, precision engineering, animation etc.

⁹ National Centre on Education and the Economy, Centre for International education benchmarking www.ncee.org/what-we-do/center-on-international-education-benchmarking/top-performing-countries/singapore-overview/singapore-teacher-and-principal-quality

¹⁰ www.en.wikipedia.org/wiki/Secondary_education_in_Singapore

¹¹ Ministry of Education, statistical digest www.moe.gov.sg/docs/default-source/document/publications/education-statistics-digest/esd-2015.pdf

¹² www.moe.gov.sg/education/secondary

¹³ Nuffield Foundation, Education country profiles: Singapore. www.nuffieldfoundation.org/sites/default/files/files/SINGAPORE%20country%20profilev_FINAL.pdf

¹⁴ Mandarin, Malay, Tamil

¹⁵ Nuffield Foundation, Education country profiles: Singapore. www.nuffieldfoundation.org/sites/default/files/files/SINGAPORE%20country%20profilev_FINAL.pdf

¹⁶ The 'A' here refers to the 'Academic route' rather than an Advanced level qualification.

¹⁷ Nuffield Foundation, Education country profiles: Singapore. www.nuffieldfoundation.org/sites/default/files/files/SINGAPORE%20country%20profilev_FINAL.pdf

The different tracks cater for different abilities and different interests. Students spend 4–5 years in secondary education. Students can transfer between streams. Students in N(A) and N(T) courses can also choose to take more academically challenging exams in subjects where they are performing well.

There are also a range of special secondary schools including: Specialised Schools (hands-on practical learning, a mixture of vocational and academic), Specialised Independent Schools (higher level study in specific subject areas eg maths) and Integrated Programmes. A number of schools offer integrated programmes – a six-year programme for academically strong pupils who prefer a more independent and less structured learning style. Students' progress to pre-university education without sitting O levels. Students sit pre-university exams after six years.

Regardless of route, every secondary school will have an Applied Learning Programme and a Learning for Life programme by 2017. These programmes offer students to pursue learning beyond the curriculum and develop life skills in authentic contexts.

In 2014, 89.1% of students had at least 5 N level passes or 3 O level passes.

There is a list of approved text books (the ATL) that schools can use. The science text books include theory text books, theory workbooks and practical workbooks.

POST-SECONDARY EDUCATION

At the end of secondary school, Singaporean students will sit for their O level examinations (express examinations) or their N level examinations (normal courses) after a four or five years of education in secondary school. They then apply for a place at either an Institute of Technology Education (ITE), a polytechnic,¹⁸ a university-preparatory school (a junior college or the Millennia Institute, a centralised institute)¹⁹ or an Arts Institution.

There are around 22 junior colleges (JC) that provide a two-year course, which works towards the Singapore–Cambridge GCE Advanced Level (A level) or International Bachelorette (IB). Entrance to Junior Secondary is conditional upon students getting an O level or N level score of below 20 (with a lower score being better). All students must also participate in one Co-Curricular activity (CCA), and performance in the CCA is considered in university entrance. Those who complete secondary and pre-university education receive a School Graduation Certificate from the MOU. It contains both academic and non-academic achievements and personal qualities. Approximate class sizes at junior colleges are around 22 students.²⁰

The Centralised Institutes (CI), named the Millennia Institute (MI) was established in 2004 to pull together into one institute all the three-year pre-university colleges. It also accepts students based on academic achievement at secondary school, and students must achieve the threshold academic level but also achieve appropriate grades in relevant subjects. Students at MI also work towards University of Cambridge Local Examinations Syndicate (UCLES) General Certificate of Examination Advanced Level (GCE A level).

Junior colleges and centralised institutes are attended by students who intend to continue in education at a local university after their two (or three) years of pre-university study. Approximately 70% of the JC cohort achieved a place at university in 2015.²¹

In pre-university education (junior college/centralised institute) students study for A levels. Students must, alongside their A levels, also pass a general paper (GP) or a Knowledge and Inquiry paper (KI) and Project Work (PW) to obtain a place at university.

Subjects at junior colleges can be studied at Higher 1 (H1), Higher 2 (H2) and Higher 3 (H3) categories. H1 and H2 are complimentary. H1 and H2 are of the same depth and difficulty but H2 has twice the breadth of H1. H1 is worth 1 Academic Unit (AU) and H2 are worth two AU. Students are expected to take a minimum of 10 AUs. It is reminiscent of an IB system. Students are also required to take one contrasting subject (eg if they are studying sciences they must take one arts subject).

H3s are worth 1 AU, but are the most demanding and promote critical thinking. H3 subjects are examined either in the form of:

- Research Papers (by Cambridge, or by local universities),
- Research work (such as the HSSRP and A*Star Research Programmes) or;
- University Modules offered by the various local Universities which are approved by the MOE.

Students are therefore able to gain extra credits and skip several modules in the university if they complete an H3. In order to do an H3 subject, students must be studying the corresponding subject at H2 level.

The vast majority of students study a science stream (12,434 students) compared to the arts stream (2,467 students).

¹⁸ Singapore Polytechnic, Ngee Ann Polytechnic, Temasek Polytechnic, Nanyang Polytechnic and Republic Polytechnic.

¹⁹ www.en.wikipedia.org/wiki/Institute_of_technology#Singapore

²⁰ www.moe.gov.sg/docs/default-source/document/publications/education-statistics-digest/esd-2015.pdf

²¹ www.straitstimes.com/singapore/education/jc-v-poly-the-pros-and-cons

There are three Institutes of Technology (ITE). They accept people based on their O level or N level grades. They provide 2-year courses leading to a locally recognised 'National ITE certificate'. They also offer certification for apprenticeships in partnership with industrial partners. Some students may choose to continue studying at a polytechnic or university after attending an ITE. The student population at the ITE is 65% male, with particular dominance in engineering (89% male) and electronics (75% male intake). Health science courses have an even gender enrolment.²²

Polytechnics accept students based on their O level, A level or ITE grades. They provide a wide range of courses such as engineering, accountancy, and nursing. They provide a more industry/skill-orientated education compared to junior colleges, and provide students with preparation for work or further study. Approximately 20% of polytechnic students went on to study at university in 2015, an increase of 5% from 2014 (due to universities increasing admission numbers).²³

| Institution | Pupil number at graduation |
|--|----------------------------|
| Junior college / centralised institute | 14,901 (JC2) |
| ITE | 11,062 |
| Polytechnics | 24,721 |
| Arts | 1,004 |
| Universities | 15,041 |

UNIVERSITIES

The Cohort Participation Rate (CPR)²⁴ for universities is at 32%, and the MOE aims to increase this number to 40% by 2020.²⁵

There are six universities in Singapore: National University of Singapore (NUS), Nanyang Technological University (NTU), Singapore Management University (SMU) and Singapore Institute of Technology (SIT), SIM University (UniSIM), and Singapore University of Technology and Design (SSUTD).

SCIENCE EDUCATION

Singapore was one of the highest-ranking countries in the PISA 2012 science tests.

The PSLE (end of primary exam) includes an exam of standard science. In 2014, 90% of pupils passed (scored A*–C) this exam. 'Science as an inquiry' is at the centre of the primary science curriculum. It states:

"The conduct of inquiry is founded on three integral domains of (a) Knowledge, Understanding and Application, (b) Skills and Processes and (c) Ethics and Attitudes. These domains are essential to the practice of science. The curriculum design seeks to enable students to view the pursuit of science as meaningful and useful. Inquiry is thus grounded in knowledge, issues and questions that relate to the roles played by science in daily life, society and the environment."²⁶

Practical skills are explicitly mentioned in the curriculum, including observing, using equipment and classifying.

In lower secondary education curriculum is structured in a similar way to the primary curriculum, with inquiry at its centre and specific skills mentioned throughout, for example:

"... make estimations and measure accurately length, volume and mass (including volume and mass of liquids and solids but not of gases) of matter using appropriate instruments (metre rule, measuring tape, vernier calipers, measuring cylinder, displacement can, electronic balance) and methods".

²² www.moe.gov.sg/docs/default-source/document/publications/education-statistics-digest/esd-2015.pdf

²³ www.straitstimes.com/singapore/education/jc-v-poly-the-pros-and-cons

²⁴ The CPR refers to the number of polytechnic and A level school leavers entering university.

²⁵ www.straitstimes.com/singapore/education/jc-v-poly-the-pros-and-cons

²⁶ www.moe.gov.sg/docs/default-source/document/education/syllabuses/sciences/files/science-primary-2014.pdf

For both the Express and the Normal (academic) routes in lower secondary 'general science' is taken, in upper secondary one science subject (biology, chemistry and physics) must be taken and students can opt to take further sciences as part of their 'electives'. They can also choose to take broader science subjects such as biotechnology and computing. In the Normal (technical) route, science is compulsory at lower secondary but in upper secondary 'computer applications' is compulsory and general science and other science related subjects (eg mobile robots and D&T) are electives.

In junior college, students studying science and mathematics A level examinations²⁷ can choose from:

- Mathematics, biology, chemistry, physics (offered at both H1 & H2 level).
- Computing (offered only at H2 level).

Students taking Science subjects such as physics, chemistry or biology at H1 only will sit for the Multiple-Choice Questions (MCQ) and one written paper. If studying these subjects at H2 or H3 students are required to take the School-based Science Practical Assessment (SPA) or a practical examination.²⁸

ASSESSMENT

The Singapore Examinations and Assessment Board (SEAB) is the assessment department of the MOE. They administer the PSLE, N (academic) level, N (technical) level, O level and A level examination.

SINGAPORE-CAMBRIDGE GCE O LEVEL EXAMINATION

Grading system²⁹

| | |
|----|---------------|
| A1 | Distinction |
| A2 | Distinction |
| A | Distinction |
| B3 | Merit |
| B4 | Merit |
| B | Merit |
| C5 | Credit |
| C6 | Credit |
| C | Credit |
| D7 | Sub-Pass/Fail |
| D | Sub-Pass/Fail |
| E8 | Fail |
| E9 | Fail |

²⁷ [www.en.wikipedia.org/wiki/Junior_college_\(Singapore\)](http://www.en.wikipedia.org/wiki/Junior_college_(Singapore))

²⁸ [www.en.wikipedia.org/wiki/Junior_college_\(Singapore\)](http://www.en.wikipedia.org/wiki/Junior_college_(Singapore))

²⁹ www.classbase.com/countries/Singapore/Grading-System

Within secondary education, students can also receive a Grade Point Average (GPA) and a School Graduation Certificate (SGC). An SGC can only be obtained if a student achieves above C6.

The Science Practical Assessment (SPA)^{30 31} was introduced in 2004 to O levels, it was a move away from a traditional practical exam and towards a school based assessment system. It is assessed overtime and contributes 20% of student assessment,³² the remaining marks come from two written papers. It covers implementing, analysing and planning. Each student is assessed twice for each skill and an average score taken. Guidance is provided on the skills to be assessed (in the form of a check list), examples of experiments, and details of equipment.³³

GCE A LEVELS³⁴

A levels are scored from grades A-E, in the same way as the current A level system in England, with 'A' being the highest grade. H3 subjects are awarded Pass, Merit, or Distinction.

DIPLOMAS (POLYTECHNICS)

These are graded in a letter system but they include AD (the top grade, referring to an A grade with distinction) and "+" grades for above average marks for each of the other grades.

³⁰ www.iaea.info/documents/paper_2fb236e4.pdf

³¹ www.seab.gov.sg/content/syllabus/olevel/2015Syllabus/5059_2015.pdf

³² [www.en.wikipedia.org/wiki/School-based_Science_Practical_Assessment_\(SPA\)_for_GCE_%27O%27_Level_in_Singapore](http://www.en.wikipedia.org/wiki/School-based_Science_Practical_Assessment_(SPA)_for_GCE_%27O%27_Level_in_Singapore)

³³ www.sst.edu.sg/wp-content/uploads/2013/08/O-Level-SPA-Information-booklet-for-students_2013.pdf

³⁴ www.en.wikipedia.org/wiki/Academic_grading_in_Singapore#Junior_college_level_28GCE_A_and_AO_levels.29

ANNEX 3: OVERVIEW OF SINGAPORE EDUCATION SYSTEM³⁵

