Use of research grade equipment and resources in a high school setting: Global perspectives and opportunities

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I am always ready to learn although I do not always like being taught

Preface

Travelling on behalf of the Winston Churchill Memorial Trust is an incredible opportunity, to be the recipient of one is humbling and in my view a reward for hard work. I was proud to have represented the both the trust and my school abroad and I am pleased to have made many lasting connections. This report represents a snapshot of the experience with some detailed recommendations to the wider education community as well as a summary of outcomes both achieved and expected. Thank you to Mark Bailey, Richard Girvan and Simon Holmes of St Paul's School for supporting the application and to Ken Zetie, Becky Parker and Tom Weller who have been sounding boards for my ideas and who both have a shared view of long term research projects in school. I am grateful to Bob Gordon of Hitachi USA for developing my list of contacts and supporting the overall aim of the project.

James Perkins, X-2017

My most brilliant achievement was my ability to be able to persuade my wife to marry me.

Then, and now...

The opportunity for travel and the time afforded me during this is something that I will remember forever. The opportunity to spend so much time researching an element of education that I believe in deeply combined with truly quality time with my family, including two pre-school children simply cannot be overstated. This opportunity was at the right time in my career and personal life and I will forever be indebted to the Winston Churchill Memorial Trust and St Paul's school.

I have relished every chance to discuss the findings, or simply to regale colleagues with stories of schools and organisations I have visited. There have already been a number of talks given prior to writing this report and the travelling has not stopped with a St Paul's trip to Brussels as part of the SPS Space Asgard project and a visit to one of St Paul's partner schools in Munich, the Otto von Taube Gymnasium. I have since taken up a post of head of science at Queen Elizabeth's Grammar School in Faversham, Kent and continue to pursue research collaborations that developed during the visits.

This is just the start. There is a growing understanding and appetite for long term independent research projects with Becky Parker's Institute for Research in Schools at the forefront of facilitating projects across the UK. I hope this report gives a flavour of what is possible as well as potential pitfalls.

Never, never, never give up

Research in schools

Motivation

"This report suggests that there is sufficient evidence to support providing all secondary/high school students with the opportunity to participate in IRP work." [1] This claim appears in the conclusions of Dr Judith Bennett's rapid evidence review commissioned by the Wellcome trust and published in 2016. She explored various types of independent research projects (IRP) from around the UK and Internationally. While there are difficulties with respect to measuring outcomes and effectiveness of such projects (typical in education research, partly due to context specificity) the general conclusion was that IRPs are positive and provide students with an opportunity to develop skills and importantly interest and enthusiasm for science.

The use of science research as a platform for an independent research project is something that I have been keen to develop. There is certainly appetite for this sort of pursuit in the schools that I have been involved with. Participation at St Paul's school in events such as the ASGARD space science project in partnership with the European space agency[2] or the IGEMS biotechnology jamboree[3] demonstrate that it is not just the competitive nature of school science competitions but the joy of participating and taking ownership of a research project that motivates them. There is also wider interest in this strand of project based learning around the world.[4]

The institute for research in schools (IRIS)[5] is a network that has been building resources and projects in which schools can participate which is generating real, published science. The variety of projects is impressive and some of the individual outcomes more so. The view from IRIS is that the boundary between high school and university is

blurring and school-age researchers are genuinely able to contribute especially given their enthusiasm and tendency to ask both obvious and unrestrained questions (of high profile organisations in some cases: NASA error corrected by school boy[6]). St Paul's has been in discussion with the founder, Professor Becky Parker since before the launch (in fact I was a schoolboy at Simon Langton when Becky Parker led her first school group visit to CERN - a turning point in my own career path). St Paul's then became a hub school for characterisation and materials science due to the purchase of a state of the art tabletop electron microscope with x-ray compositional analysis capabilities.[7]

Much lauded 21st century skills are a key benefit of IRPs and research in schools. The development of IRPs via science research projects (including the EPQ) has great potential in this area and the EPQ is specifically designed to help train students in these 21st century skills.[8,9]

Since the school purchased the Hitachi TM3030 scanning electron microscope with x-ray analysis I was keen to develop its use in three areas; enrichment, research and outreach. I believe the instrument is an example of a research-in-education model that could be developed in different departments and is an exemplar of how the school can provide a broader and deeper education alongside positive community projects that also have potentially deep and lasting impact. The SEM is a research-grade instrument that is widely used in university research labs and industry alike. It is not a 'pared down' version, indeed the x-ray analysis and tilt-rotate stage are additions rarely found in many labs. My belief is that students respond to being able to use such equipment themselves for their own work much better than any demo or brief laboratory visit. Schools associated with IRIS clearly believe this and we have worked with a number of schools to develop projects and foster collaboration between students.

The school has worked with small businesses, professional organisations and a number of state schools to facilitate outreach events, develop a research program and enrich the science experience of its students. It was for this reason that an idea of sustainable good practice became important so that the microscope did not become a rarely used toy of privileged private schoolboys but was able to reach the wider school-age science community.

Inspiration?

Funding?

Expertise?

Resources & Equipment?

Time…time…time…time

To that end, the focus of my fellowship was three-fold.

1. *How similar or equivalent research-grade equipment (including some schools using the identical model SEM either purchased or on loan from Hitachi) is used in a high school setting.*

2. *How research in schools may be facilitated within the constraints of high schools and whether US or German systems could be implemented in the wider British education systems and how schools have overcome common challenges.*

3. *The logistics and implementation of outreach programs - from business (e.g. Hitachi's loan of their SEM), Charities/NGOs and schools themselves.*

In context: Understanding the USA education system and role of external agencies

Nancy Healy, Georgia Institute of Technology/National Institute for Nanotechnology & Linda Rosen, Change the Equation.

Nancy Healy is a true advocate of research experience, not just high schools students but across the board. The research experience program in the United States is interesting as it allows high school teachers to embed themselves in a research group for part of the summer break. They can participate in real research and this helps provide inspiration and resources for lessons. A fantastic example of the outcome of this program is Mike Boyer at North Penn (see below). Nancy also favours the approach that allows students to experience using real science equipment and believes the 'real thing' enhances their experience of science (I met Nancy at Georgia tech, only moments away from the Coke museum). While her specific interest is nanoscience, for example the use of the Hitachi microscope at outreach events,[10] our discussion was much more general and encompassed other areas of science and the challenges associated with trying to recruit and retain a skilled, experienced teaching workforce, a challenge mirrored in the UK. Expertise to support IRPs is a challenge, but wide networks and support (including a variety of funding streams) from professional bodies is something that teachers in the USA are able to access. One challenge we discussed at length was the recruitment of teachers who have research experience and the idea of ensuring that teaching could be seen as a viable alternative to academia or industry. As the opportunities for IRPs grow maybe the distinction between university/industry researcher and teacher-educator researcher will become more possible and ultimately appealing.

Dr Linda Rosen is CEO of 'Change the equation,' an organisation that facilitate projects working with disadvantaged groups in an education setting. Under the STEMworks[11] banner, projects have to meet strict criteria since the funding is coming from various sources including big business that are looking for a return on investment in terms of an upskilled pool of potential employees.[12]

Studying advanced technology itself (i.e. how it works) and where it is used in genuine research projects (or better still, allowing school children to undertake their own research projects) stretches, challenges and develops problem solving skills. What may be missed is the combined opportunity for engagement and enrichment for younger students or those that may not have thought about STEM subjects or careers. While pre/post activity surveys have their faults they do show up positive outcomes where student have participated in a well-designed outreach event involving use of research methods or equipment. Just as an inspirational teacher can change the path of a student, access to and genuine hands on experience of STEM research techniques or equipment may be that 'fork in the road' where a student decides that she wishes to find out more about a STEM career or look to take that advanced placement class. For a student from a low income, low aspiration household even a small change in pathway could ultimately have a huge impact. Tracking or evaluating long term outcomes is difficult but Dr Rosen was keen to discuss the idea of 'pathways' within the education system, something that can be monitored effectively; for example, introducing elements of coding into elementary school classes that are then taken up by the student at middle school and lead to aspirations of a career in IT.

The interesting idea to bring back is the cooperation between different stakeholders, often including the business/industry link. Just as Nancy Healy spoke about networking in the broader picture of 'outreach' and the 'research experience' programs I have been surprised and delighted by how much some companies have been getting involved with grassroots education projects. Moreover they seem to share the same ideas of what should be on the curriculum and how it may be taught. That is not to say that teachers are being told how to teach, more that a collective discussion can take place and useful resources produced to help teachers.

What is fascinating is that the questions about funding, resources, barriers to participation, availability of subject specialist teachers and the governmental pressure to look at international league tables (such as PISA[13]) seem to be the same as in the UK. The solutions are influenced by cultural and historical factors unique to the US and hence there is a slightly different approach and demographic target compared with the UK.

- The research experience program relies on a relationship with local universities and research institutions. The UK has many world-class universities and multi-National companies. More thought from universities on how they can work with schools over a longer term with true partnerships and genuine projects.
- Recognising the need for at least a network or access to a network of expertise in order to best support IRPs but also the advantage of continuing to recruit teachers from academia and industry to provide the best support for an enrichment program beyond the syllabus.
- Tracking outcomes of outreach or enrichment activities is difficult, however a discussion about methodology and ensuring feedback is always collected after an event will provide some data. Pathway changes are more difficult to track although methods such as monitoring destinations of school leavers via linkedin or equivalent (at the level of self-defined occupation) may work.

Biobus

Biobus was the single most inspirational organisation led by an incredible, truly altruistic and charismatic character Dr Ben Dubin-Thaler. [14] The Biobus is a mobile laboratory staffed by a small team of full time Biobus scientists and regular volunteers. Many of them have an academic background from top US colleges and have chosen to pursue education provision via biobus rather than becoming a regular teacher or academic. It is the fact that they are experienced and well qualified academics which glues together the whole project.

The bus is a fully equipped microscopy characterisation suite with three ‘dissecting light microscopes’ with CCD camera output to monitors, hand held microscope with video camera, another DLM with a large monitor and the Hitachi TM3000 table top SEM. Biobus gives schools the option of running their own prepared lessons or respond to the needs of the particular school. Each day is split up into classes to accommodate the timetable of the school and groups of students participate in a variety of activities during the lessons. Talking to teachers from participating schools it is clear that the children from disadvantaged areas often do not conduct experiments at all due to lack of resources let alone use such advanced equipment. The bus is completely hands on and the lessons that I observed were all very discursive encouraging open ended questions while proceeding with a set experiment or activity.

Many schools hire the bus more than once a year and most will rebook the following academic year (cost depends on the financial situation of the school, it can be free or they may pay a contribution). The staff scientists are positive role models (with ethnicity and backgrounds) and as recent PhDs or postdocs can be closer to the age of the students than their teachers.

They have recently opened up a second ‘BioBASE’ which allows students to have additional science activities and lessons outside of regular school. I visited the original lower East side BioBASE and witnessed a fantastic food technology session (materials science taught using common ingredients). There was real trust between the very disadvantaged children who were attending and the Biobus staff. It was a safe space and they were encouraged to ask all the great questions that asking in school may have led to bullying or ostracism. It was a humbling visit but proved what science outreach can do when run effectively.


The biobus and biobase lab (bottom right)

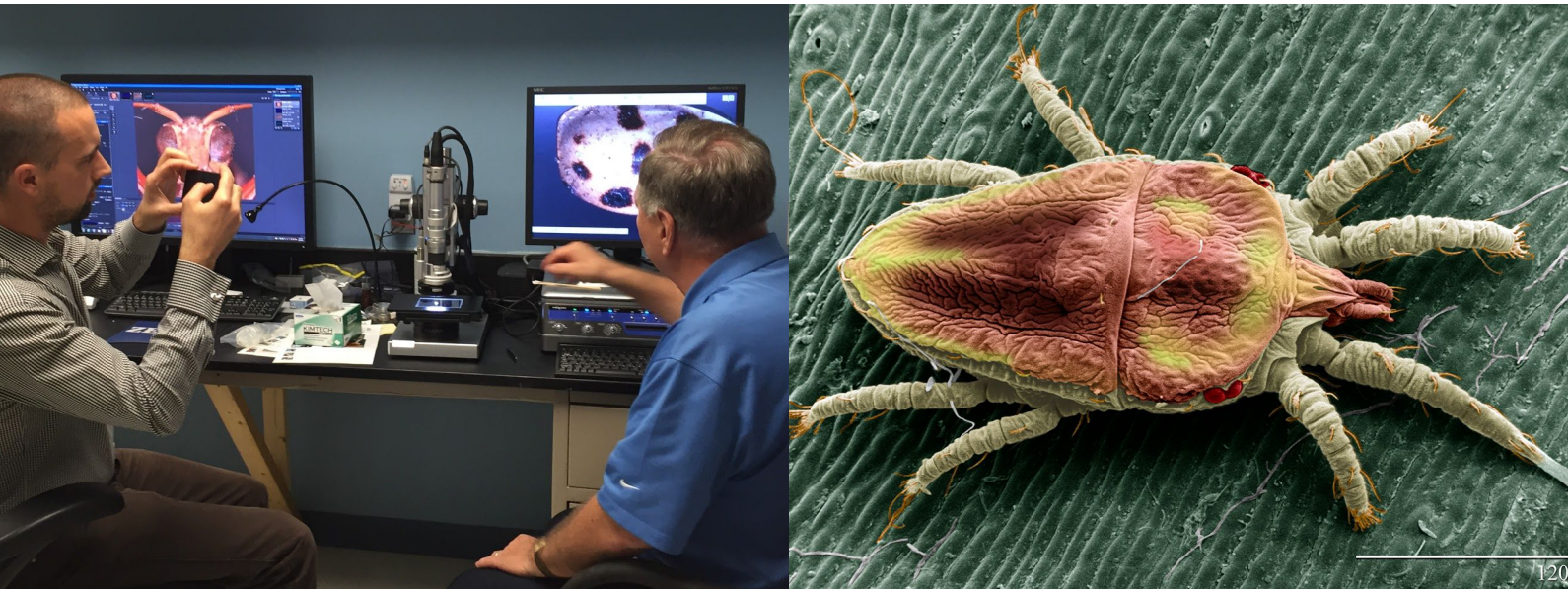
- In the London area there are many graduate students and postdocs who are keen to be involved with outreach events. The STEM ambassador program is an excellent example of bringing scientists and engineers into the classroom. Again, the ideas of partnership and longer term projects need to be added to the mix.
- A safe and accessible space was important for the participants at Biobase. Thinking about where outreach events take place within the school will be important for the engagement of the students. While it is fantastic to have any peer to peer teaching, it is vital to remain sensitive to the needs of the participants (who are we doing this for?)
- The combination of the bioBUS and bioBASE make this organisation especially effective. Cultural capital is easily acquired - evening visits to the theatre, cinema, drama and sports clubs. However, science has limited opportunity to become part of the community. The BASE is an independent after school club that can fill this void. Do such places exist beyond the burgeoning maker space community in the UK?

USDA - US department of agriculture

Dr Gary Bauchan made me feel very welcome at the USDA, just north of Washington DC. Having worked at Oak Ridge National Lab in a past life, the atmosphere at the agriculture microscopy labs felt very familiar. The key message here was the access available to high school students to do genuine, useful work and being trained on all the state of the art equipment used on a regular basis at the lab. Each year a number of students from local high schools spend time as interns in two ways; firstly a regular research experience summer placement (in fact they host teachers as well - part of the aforementioned research experience program), secondly, and not unusually in the DC area, students from high school will spend a considerable amount of time during the school year at a chosen placement. This may be every morning except Friday for an entire academic year (equivalent year 11) in the case of Eleanor Roosevelt High School, or another model similar in scale and ambition. This is an incredible opportunity for the students who are able to fully contribute to research efforts at the lab. One of the recent students had been trained on the scanning electron microscopes to acquire high resolution images of 'mites' and then used very high quality optical imaging and colour analysis to false colour the SEM images for publication.

The equivalent would be labs such as the Diamond light source, Kew gardens or National Physical Laboratory opening their doors to school age researchers for long-term projects (a whole academic year). Pfizer's community lab (for example at the discovery park in Sandwich, UK) is a great example but it would require expertise in the individual school to be able to facilitate a long term IRP.

- The notion of such a long term internship or work experience program would be hugely ambitious and logistically difficult. However, through networks of parents and local businesses/academia this deep level partnership would provide incredible opportunities. There is little to recommend other than open up a discussion about the possibilities and challenges. However, an enhancement to the curriculum of even half a day working for a year with some sort of written outcome (maybe to extend volunteering) for an entire year group could be incredibly powerful.



Dr Perkins, Dr Bauchan & a mite, but which is which?

School visits

Bergen County Academies

Bergen County Academies (featured in the book "exam schools"[15]) is a rather difficult school to understand because in its current form is only 20 years old and is still finding its feet and because their approach is so overwhelming for someone interested in students undertaking research projects. It would be incredibly difficult to emulate in the UK but there are plenty of ideas that schools could explore.

The formidable nano-characterisation facilities at BCA. Including a dual beam focused ion beam/scanning electron microscope (centre) and a lanthanum hexaboride source transmission electron microscope (near right); two pieces of equipment I have only ever seen in research labs.

BCA's history is as a vocational college and, while it is located in the suburbs of New Jersey in a relatively wealthy area, students are selected from various locations and there is certainly a demographic mix in the school population. My host for the visit was Dr David Reeves (from Birmingham, England). He was originally employed for technical support due to his experience in the maker program in NYC, but is also mentoring a number of research students and will be teaching regular classes next year. David is a PhD microbiologist and electron microscopist, he's an electronics whizz and seemed to have an active interest in photogrammetry (among many many other things). All of those skills are not just of interest to the students, but vital to their chosen areas of research.

The structure of the school, the timetables of staff and students and the technical support is all geared towards research. The principle, Russell Davies is quite clear about the vision and how the school not just supports science research but the whole ethos of the place is based on students undertaking active long term original research. The concept is embedded in the life of the school – not for exam success (that already happens) but to prepare gifted students for the next stage in their lives with skills needed for 21st century careers and challenges.

Much of the detail can be found on their research pages;[16] examples of genuine research using state of the art technology that has been presented at International specialist conferences like 'microscopy and microanalysis'.[17] To facilitate this a number of things are in place;

- Timetable and school structure. BCA has an extended day running from 8am until 4.10pm with timetabled classes. Like any school there are extra-curricular clubs and societies that meet outside of these times, but importantly the research program sits within the timetable and so students have official time where they are supposed to be working on projects (although inevitably they end up in the lab rather more than their allocated timetable time!)
- They are lucky enough to be able to arrange teachers timetables to provide lots of lab supervision and mentoring time. This is to allow the students as much time in the lab as possible (i.e. anywhere where research is taking place – the microbiology lab, the nanoparticle synthesis lab, the robotics facility, the virtual reality suite etc.) and importantly access to mentoring.
- Staff expertise. Much is made at BCA of staff having 'past lives' – ex-academics or people working in a variety of industries. Those experiences and skills that can be mined by students. Departments can adjust the loading of staff depending on numbers of student researchers, some teachers excel at teaching core courses others can concentrate on the advanced placement or provide elective 'introduction to ...' particular research programs which are taken for credit that counts towards the student's final high school grade.
- Equipment. As an ex-vocational college in a wealthy area of the country, BCA enjoys a healthy 'per student' funding arrangement. This goes a long way to providing the sort of staff flexibility that can facilitate the research. This is absolutely fine in itself but the vocational thread allows extra funding geared towards training specific skills. These are 21st century vocational skills; nanotechnology, coding, advanced microscopy, genetics etc. and hence their labs are well equipped. This is equipment you would find in a university research facility let alone a university teaching lab.
- Wednesdays! A surprising element of each week is the Wednesday project. While there are some regular classes, for two hours all except the seniors sign up to a year-long project. This in addition to any personal research projects and there is no restriction on what they can choose. It is a group project and the variety is phenomenal, from building mandarins to setting up a biotech company (the school has an IP lawyer on retainer because some of the work coming out of the Wednesday projects has real potential!)
- Senior Wednesdays. While the rest of the students are working on their group projects the seniors spend the day out on an internship. Another example of where internships are very much part of the culture. Unmeasurable impact when it comes to exams but BCA believes very much that this experience enhances the student's skillset when they leave school.
- The maker-space. As a vocational college the school has an adult education building but this is well used each week as a maker space. With David Reeve's experience in the maker community they were able to secure funding for equipment and it works as a community outreach hub. Students often help out or use the equipment for their research projects.

- Changing the structure of the day was a theme evident in a number of schools. Thinking creatively about how to use the school timetable could facilitate plenty of activities without affecting either the demands on the students or their academic work yet provide real opportunity for further community, enrichment and broadening activities. Thinking beyond the traditional school day in the UK would be essential given the number of examined subjects taken at most schools.
- Further community projects (such as the Wednesday project) which bring together different year groups could work well at many schools, especially if running a 'house' system which brings an element of competition to the projects.
- Ambition. Both in terms of seeking funding and the type of research that is happening, with the space given to research it is incredible what can be achieved. BCA believe this has improved their college application success and colleges such as MIT are specifically targeting BCA students.

Challenges:

- The constraints of GCSE/A level education system need to be thought about carefully. The key word is 'facilitate'. The US system of four years of high school allows the potential for greater depth of study while keeping a broad curriculum. Now that post 16 education or training is compulsory, what role do GCSEs have. Are the exams at 16 holding back bright students while disengaging those that are strong in a particular area? Is there an alternative model that can maintain breadth and depth as well as engagement?

Clockwise from top: Coating technology for use with electron microscopy samples, a gas-exchange-capable confocal fluorescence microscope, the BCA maker space in the adult education centre, virtual reality lab featuring the virtual 'Ellis island' designed by students for the National Parks service.

Southampton High School

My assumptions about the school given its location in the Hamptons, Long Island were quickly put right by principal Dr Brian Zahn[18] and Greg Metzger; oceanography & marine science teacher and research enthusiast. Southampton has a large immigrant population and the permanent residents are not necessarily those in the mansions. There is a permanent population that remains beyond the tourist season and there are some big employers such as Brookhaven National Lab and Stony Brook University in the vicinity. Southampton is non-selective and there is the full range of abilities and needs amongst the students. Yet, with resources limited and spread well beyond the needs or wish list of the science faculty they are still opening up the timetable to facilitate long-term research projects. For Greg Metzger there is a huge opportunity; *"Research is not just for the bright kids who collect all the [advanced placements], they probably won't have the time to dedicate to it, it's for everyone else to get the opportunity to experience something beyond their regular classes.*"

Southampton High School represented two elements of research in schools. Firstly the variety of research programs depending on the expertise of the staff. Secondly the dangers of not providing the structure or supporting the staff/program adequately.

I was very sad to see an SEM identical to ours not being used, nor plans for it to be used in the near future. There were no trained staff (currently) who could subsequently train students. The lab was empty and waiting for a restructure of the school timetable. A quirk of scheduling meant that many of the students who wished to take an independent research class were no longer able to do so. Amy Page, who has taught at the school for 19 years and now heads up the research element was keen to press a now-familiar theme; "*The schedule for the students must work, there have been changes that have inadvertently led to a drop in uptake for the research program*." However, the very fact that there are funds available and timetabled time makes a huge statement about the benefits benefits of research. Dr Zahn mentioned another recognisable element; "*High school graduates are ill-equipped for the modern workplace, they must be able to experience failure and learn problem solving skills.*" However, in the marine biology class, research is ongoing as part of the curriculum and a number of independent research projects are happening within that department. Confusing school politics and timetabling structure has led to this situation and is a danger when a critical mass of people and/or decision makers cannot support the project.

No students using the SEM on the days I visited.

Southampton high school marine science research laboratories and oceanography tanks.

- Do not allow the equipment to be a show-and-tell item, it must slot into different areas of the school activities. The natural combination of enrichment, research and outreach allows different people to be using the equipment for different activities. While there may be crossover, as long as there is still a variety of interested staff the equipment and program can continue.
- Look to different departments to think about genuine research. In many ways science research may be limited by access to equipment but other subjects may only be limited to time in a library.
- Look at IRPs as a way of engaging those below the top tier of students. There are many that have a more practical/investigative nature, the 'tinkerers' or simply those that have historically not performed to their potential in examinations.

Challenges:

- Equipment that is left unused or staff who are not fully trained is a problem faced by all centres using advanced equipment. Longer term strategy for supporting the program is advised (including the budgetary requirements of service contracts etc.)

- Equipment will at some point no longer be up to date or state of the art. A commitment to a program using often expensive research tools needs to develop and grow. Some consideration within the longer term strategy would need to include the point at which the equipment is replaced or renewed.

Princeton International School of Science and Math

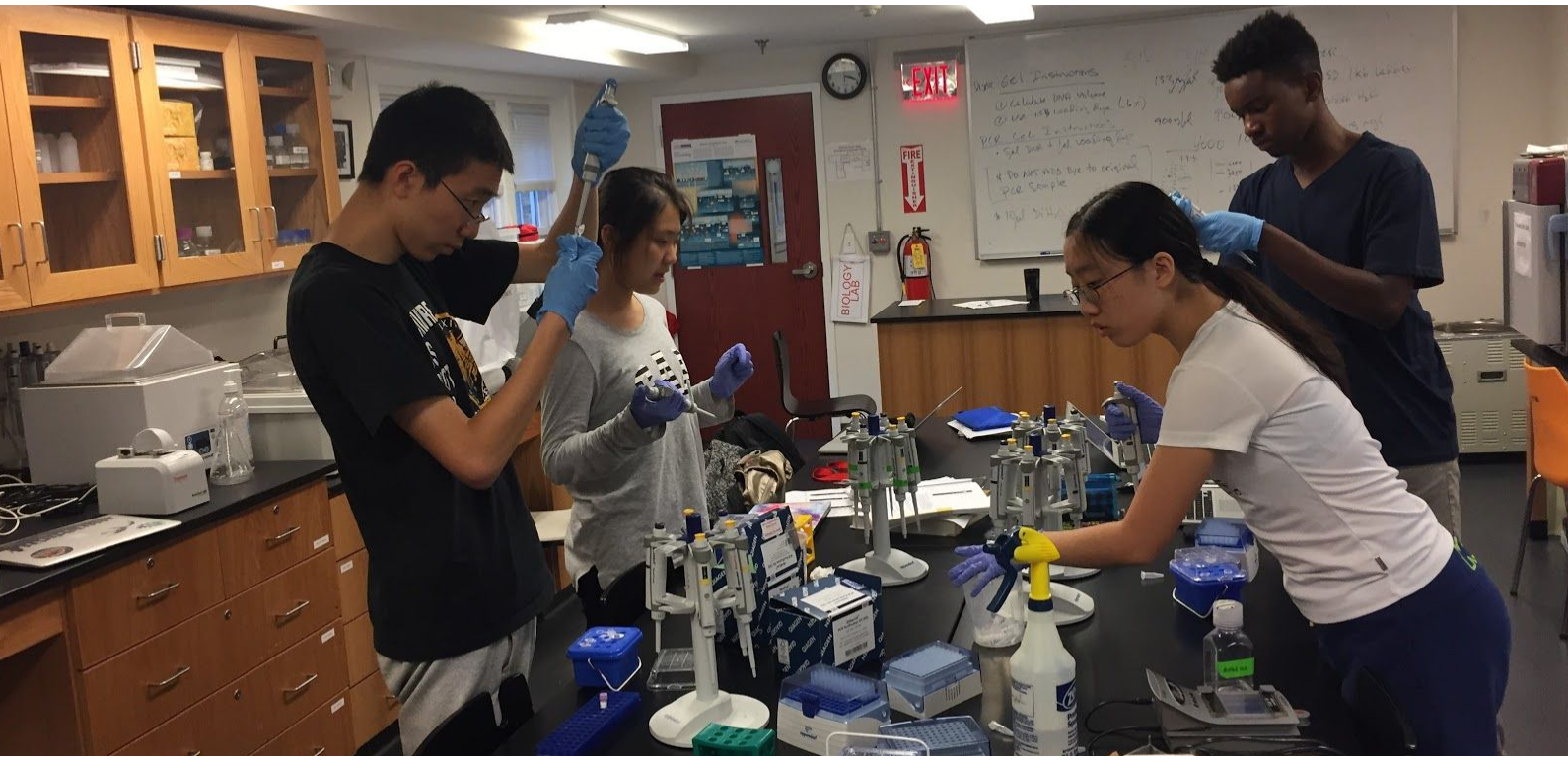
PRISMS is a very new school indeed, set up four years ago by a number of teachers from the formidable Thomas Jefferson High School[19] (itself a pioneer in high school research.) It received private funding from a major benefactor and has been able to design the curriculum from the ground up following TJHS brand of research-led learning in sciences and engineering. It is an International school with a large number of students from Asia and the far East but follows a broadly US format with students able to take AP and 'post-AP' electives.

There is a requirement for a minimum level of English but most students have English as their second or third language. There are very small class sizes (I'm not even sure you can call them classes, they are mini research groups, even in their 9th grade humanities classes!) With the Princeton location this little private school is competing for students amongst some excellent high schools and in an area with high property taxes. It has certainly found its niche with science research at the very core of the school. Timetable design is led by the research and the graduation requirement includes the research project that will take at least two academic years. The humanities and arts subjects are involved in many cross-curricular themes and activities. For example in English class the students are required to write a technical report based on their work in science. They find context to their research in history. While not universally popular with the humanities teachers there is the understanding that the structure is based around the science research project and for the students it helps to understand where science fits in wider society.

I was delighted that PRISMS managed to present at the St Paul's International Science conference via Skype during the poster session. Their principal, Matthew Pearce (ex-Latymer physics teacher) attended the conference in person. This was a very special visit proving their wish to develop International research links for high school students.

Dr David Hauser,[20] chair of the science department and lab director (defined by teaching a research class) for microbiology and 20 year veteran of the biotech industry is absolutely clear on his role which is to facilitate high quality, original research using state of the art techniques. They are succeeding and the proof appears to be born out in college places.

David Hauser's concern is the ability to collaborate. He understands the research world well yet feels that schools generally operate behind closed doors. He would very much like to see a global network of research schools where students can be found talking to their peers from different parts of the world; "*...there are few schools in the US and UK that are using authentic science as a teaching platform and most of these are working in isolation; improving discourse between these schools is badly needed.*"



The biotechnology labs at PRISMS

- Foster these links; Schools such as PRISMS are excited by the potential for collaborative research (in many different fields of science and engineering) and are excited by the possibility of a global network of schools undertaking this type of activity.
- Ensure methods are available for students to communicate effectively with their International collaborators - this is a challenge with many schools blocking networking software such as Skype or Viber for student use. Schools will need to have a more forward thinking ICT policy to facilitate collaboration methods.
- Think about the timescale of projects and how to link in with existing programs such as the EPQ. Projects do not need to be single year or indeed have expected 'final outcomes' within the academic year. Part of 'real' research is handing over ongoing projects to the next group of researchers. At every level the experience should be authentic and this may well be undertaking a small part of a wider project.

Challenges:

- Maintaining a collaboration can be difficult in the normal work life of a school, more so if the distance is greater. Add the time zone issue and careful planning of even a simple interaction becomes more difficult as we found when PRISMS presented via iPAD at the International Student Science Conference at St Paul's, March 2017.

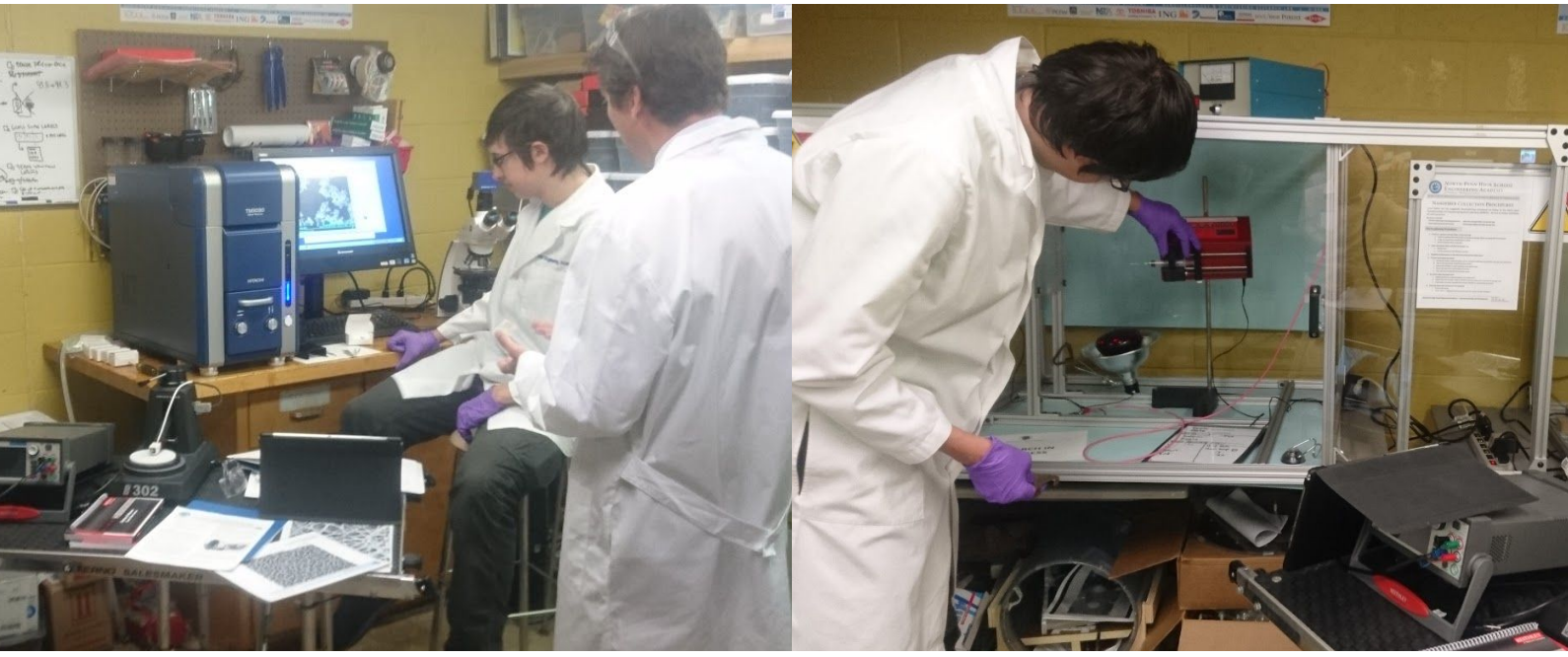
North Penn High School

One of the key outreach models in the US is run by Hitachi. Bob Gordon, vice president, based in Pleasanton, CA, has an incredible program that provides the same model SEM (albeit without x-ray analysis) to go into schools on a longer term basis than simply a day or two. This provides enough time for planning curriculum and ensuring a much deeper experience for the users. The teachers and responsible students are given the opportunity to become fully trained and can therefore run lessons with minimal external support. This can provide enrichment for students and deep impact outreach for research programs who need access to such equipment. North Penn has been the recipient of the loan SEM for the past few years.

North Penn high school is a vast and complex operation. With over 3000 students from all backgrounds and a huge variety of abilities. This high school caters for the whole community. They have a phenomenal sports program, a cadet force active at 6am every day, a strong support structure for those with special educational needs and the full gamut of AP classes to stretch the brightest. Mike Boyer has lit a metaphorical firework in technology. As a new department chair and with an enthusiastic team behind him the department is going from strength to strength (with expansion likely next year leading to students gaining college credit if they take the full range of technology electives via 'project lead the way') and has Mike's research class as the jewel in the crown.

Mike Boyer, second left, with Engineering faculty staff at North Penn HS.

Whereas most of the visits have centred on teachers with particular backgrounds in science or technology, Mike Boyer's journey was a little different. Having found his way to education Mike very quickly looked for opportunities to further his understanding and skills and took the opportunity to get involved with a research experience program for teachers at Drexel University, Philadelphia. Being part of the research community, Mike found that the process of research was inspirational, not just for his teaching but in the application to the way students learn; "*Students have to learn, not memorise, [they have to] experience it.*" Having found the program a positive experience he went back the following summer, wrote a whole new curriculum and then went back for two more summers while formulating the now-successful nanotechnology research program; "the future is N.E.A.R" (nanotechnology education and research). Mike firmly believes that the students gain much more from the research experience than from traditional lessons; "*everything [they do] is applicable… [they have to] reflect back on previous work, what they did, why they did it… the growth mindset*." [21]



Electron microscopy and electro-spinning at North Penn

As with the other schools, the research is facilitated by two key things; the teacher and time. However, thus far Mike has had to apply for funding of his equipment through a range of grants and industrial sponsorship. As an elective class, there are limits to the level of funding available from the school. His students request the equipment that they need and Mike makes every effort to build it in house or purchase. They are up to three electrospinning chambers in addition to regular short term loans of a tabletop SEM to characterise their nanofibres. Being within the technology department means that adaptations to the 'standard' setup are easy to build in the workshop next door or on one of the bank of 3D printers.

The school is now looking at how to expand research, certainly in the science department, but also with the added bonus of an AP research program that would be subject agnostic, much like the EPQ. The AP research is a new curriculum but certainly proves that education decision makers are looking at research techniques as a serious element of high school education.

We were delighted to welcome members of the N.E.A.R. class to London. They presented their research at the International student science conference and enjoyed a day at St Paul's visiting classes and using the SEM. All funding came via parents and a crowdfunding initiative for disadvantaged students.

EPICS. The '*Engineering Products In Community Service'* club was set up at North Penn based on a program run at Purdue University.[22] Students research and solve problems that are relevant to their own community, in this case within the school. This club follows a research model and engineering design principle and this year's cohort are working on a variety of interesting projects including a speaker button that will aid children with special educational needs that find it difficult or are unable to communicate verbally. In this class I saw many of the same faces that are in Mike's nanotech research class, when asked why they were there they simply said "because it's fun". For those that are worried about metrics, that answer says a lot about their experience in research classes.

- Enrichment; clearly the SEM is a key part of the characterisation work for the projects on the N.E.A.R. program. It facilitates the next level of research without relying on the administration and logistical challenges of a school visit to a university (even if the local university was amenable and could facilitate access to the equipment).
- Outreach - the long term loan model works very well. Deep impact (with students fully trained and doing their own work on the instrument), tangible deliverables (could include contribution to EPQ or other IRPs), will almost always generate publicity and local news stories (and indeed could be part of the loan agreement, Hitachi are keen to log outreach event reports to help assess the genuine impact of the project. Our program at St Paul's included a trial for the long term loan model with Simon Langton Grammar School in Kent. It was successful and contributed significantly to the work of a number of students in their IRPs.
- Research; a great opportunity to develop networks of schools and collaborative work between students. The networking element is exciting - one school may have the equipment, another some specialised expertise, both sets of students will gain.
- The EPICS program could be easily transferred with a community focused engineering and science research project with the equipment and/or the expertise put to community use.

Challenges:

- Logistics are not straightforward for the SEM. Hitachi are looking to expand their outreach program in the UK but require a network of experienced operators to support the SEM in schools. There would be a similar requirement for any advanced scientific equipment.

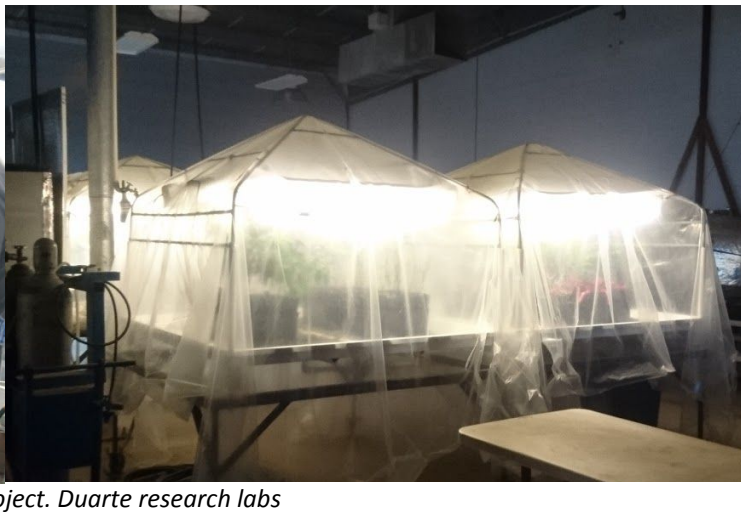
Many of the students in this photo came to London to present at the Student Science Conference

James Enochs High School

Dave Menshew has a much more curriculum focused approach. This means the SEM use is higher than for IRPs although the depth of training for any given user is somewhat less. However, as a self-contained set of lessons seeing the 'real' equipment is a huge boost and anecdotes abound regarding inspiration to pursue forensics at college and beyond. It also provides a further opportunity for the school to run outreach sessions involving the microscope, thus showcasing the technology to a much broader audience. The microscope was in situ for two weeks during a 'case study' event for the forensic biotechnology students (Forensic biology is a year long elective class run by Dave Menshew). The SEM has been part of the program since 2014 and has been a successful addition to the curriculum.[23]

The loan agreement was similar to the North Penn HS agreement in that during a concentrated period of time the SEM is used by a number of students and/or classes to aid their research and/or enhance the curriculum. While there was limited time for training by Hitachi, the teachers are fully trained on the instrument and in some cases senior students are trained as well. There is limited support by Hitachi, partly because of the distances involved for technical support.

In addition to the forensic biology, Dave Menshew has an active interest in real research in schools. He has spent the last few summers working as a plant scientist at Duarte Nursery, a local farming business with agricultural research centre. [24] This has led to a collaborative research project studying salt-resistant strains of pistachio plants. The area in and around Modesto is a huge agricultural region with horizon to horizon orchards of Almonds, citrus, pistachio etc. The recent droughts in California make the research incredibly relevant to the students.



Students from James Enochs HS working on agricultural research project. Duarte research labs

- In many cases whether short or long term there is a requirement for curriculum resources to support access to advanced equipment. Dave Menshew has a standard 'case study' that he can use to support the equipment. Development of curriculum material would work best if in collaboration with the instrument manufacturer or outreach organisation. However, in terms of IRPs appropriate training for staff and likely users (the students themselves) would need to be part of any loan agreement.

- Forensic science is a great example of a science cross-curricular opportunity. There are many opportunities to bring together arts/sciences/humanities with specific advanced equipment at the heart of a project.

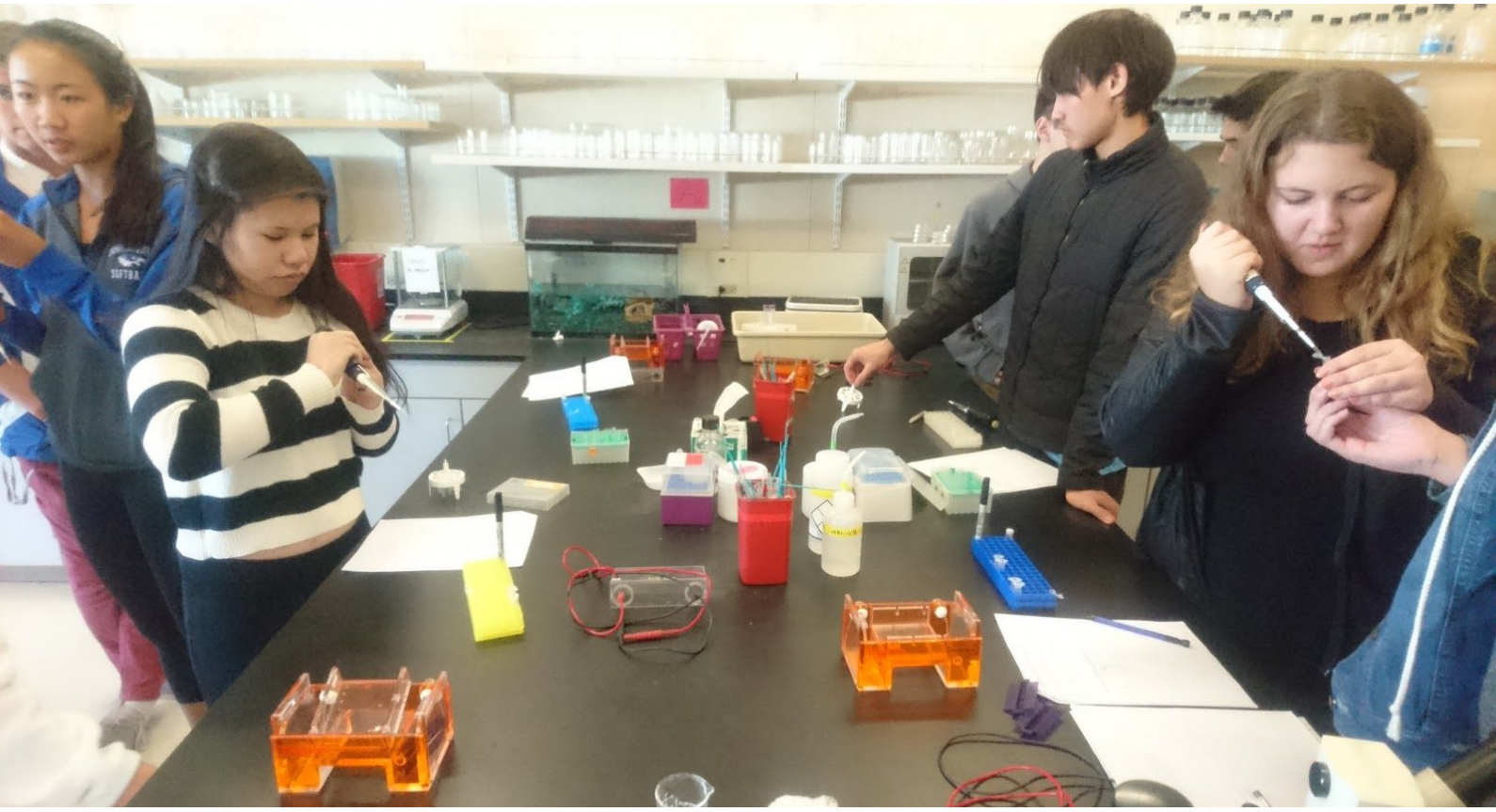
Los Altos High School

Los Altos HS is in the heart of google and Apple territory; Mountain View, California the centre of silicon valley. Again this is a public (maintained) school but it very much benefits from location. The school has a couple of funding sources that probably couldn't be compared elsewhere; google and the parents 'foundation grant' scheme. While Los Altos is a public school, it gets no top up money from the state of California as property taxes in the region are so high, moreover Mountain View is the home of google and there seems to be a huge amount of philanthropy in the area especially towards education, from past students and from local businesses, big and small. This enables the department to fund some of the more ambitious lab experiments and research ideas. The parents group, again by virtue of being local to the school are a great resource and the science department has successfully applied for a number of items, including the electron microscope.[25] In addition, I heard about the occasional giveaways of surplice equipment by local businesses and colleges that the department enthusiastically seeks out.

Silicon Valley's take on staff parking provision.

As with a few of the schools I've visited the science department at Los Altos has managed to persuade the district to facilitate a science research class. It has an average of 50 minutes per day and is a year-long course made up mostly of Juniors and Seniors (year 12 & 13). The bulk of the first few weeks is taken up with literature review and identifying possible mentors from academia and industry. The advantage of being in Mountain View, Ca becomes obvious with the wealth of science and technology universities and businesses in the vicinity. However, it was very interesting to see how far they had cast their net including a professor from the University of Derby, UK. They have started to build up a database of past mentors and have maintained the relationship, often inviting them to give talks during the school district science week. Research class teacher Darren Dressen is clear that continuity helps, i.e. previous students being able to help current students with their projects, or taking over where others left off. Dressen tries to facilitate their equipment requests but the research class is not directly funded by the school so the department has to be imaginative about getting hold of the research equipment they need. The projects are incredibly varied and don't necessarily follow the expertise within the department – the experience of the science teachers (many of them previously from industry or business) can help with the broad skills needed for research but the students themselves seem to be incredibly self-motivated. They have no problem contacting and chasing up their mentors when they need assistance and have to produce detailed, fully costed specifications of what equipment they are after! Maybe this comes from a confidence gained in their other science classes.

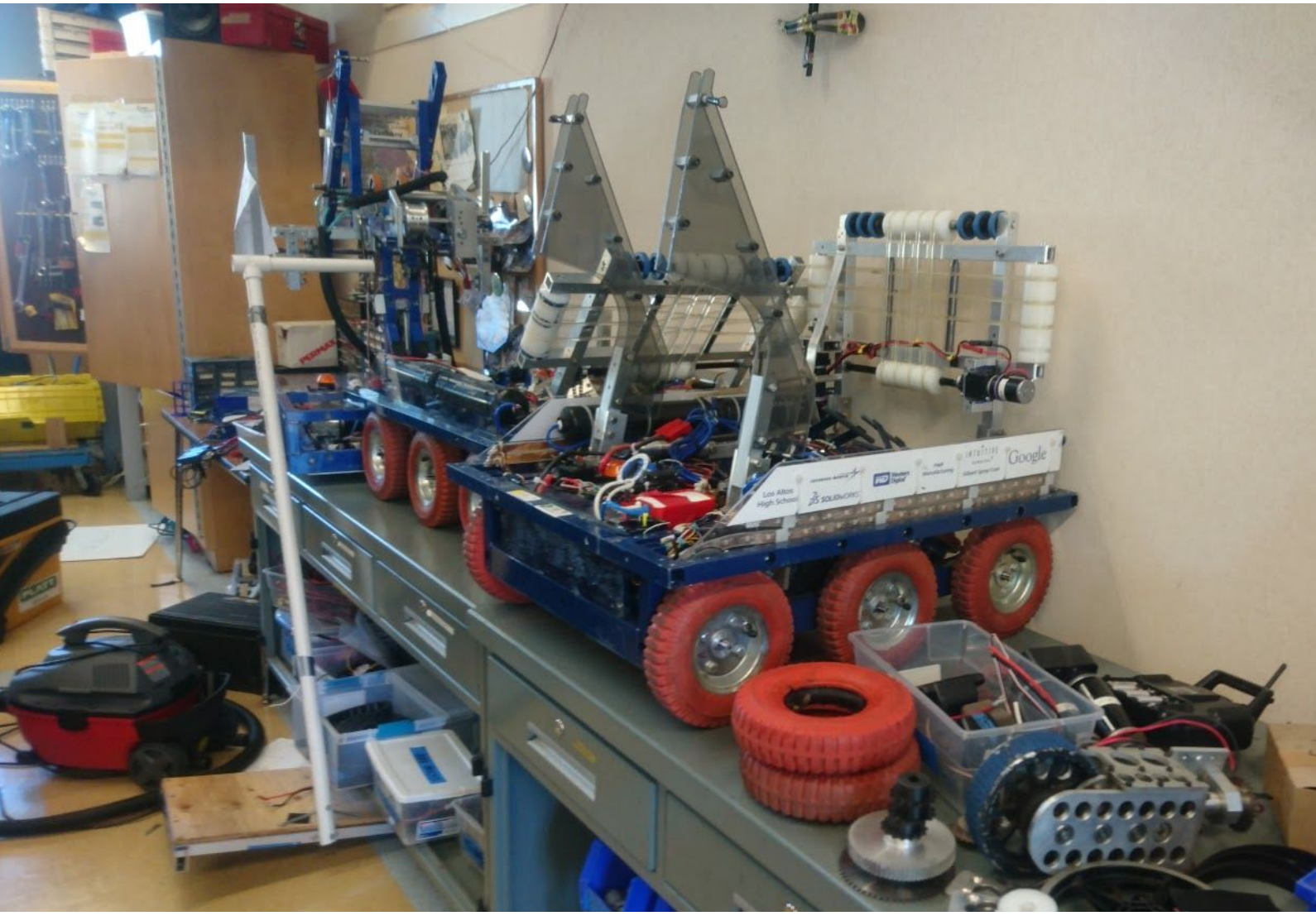
What amazed me was the level to which research methods and equipment that you'd find in academia or industry was embedded within regular classes. The scanning electron microscope seems to be used within a number of different subjects for a whole variety of laboratory experiments (during my visit a comparative study of sea plankton from locations along the coast were being imaged). The department is still learning and it was nice to be able to share some of my expertise regarding sample preparation and image analysis when discussing some of the experiments. In addition there was a whole class set of biotechnology equipment that is rather unusual – although I am beginning to see biotech work its way into classrooms more often. I've never seen several sets of gel electrophoresis being set up in a laboratory skills class. Moreover, these techniques were being taught in honours biology as well (possibly an equivalent of year 10 or 11 biology GCSE classes.) DNA splicing with the end result being bacteria colonies expressing the gene for red fluorescence from sea anemone within a regular class setup was very special. The students realised it too. One of them mentioned to me that he had a good grasp of different areas of science and engineering purely because he lives among all the high tech companies and it is hard to escape their influence. It isn't just the equipment facilitating research-led approaches. I was very interested to see every lesson packed full of investigative, project-led, teachers-as-guides tasks. This meant that by the time the students were working on the more advanced laboratory experiments or developing their proposals in research class they had a good feel for the skills and methodology required.



Honours biotechnology class (year 11 equivalent) - a specific class teaching experimental techniques for biotechnology careers.

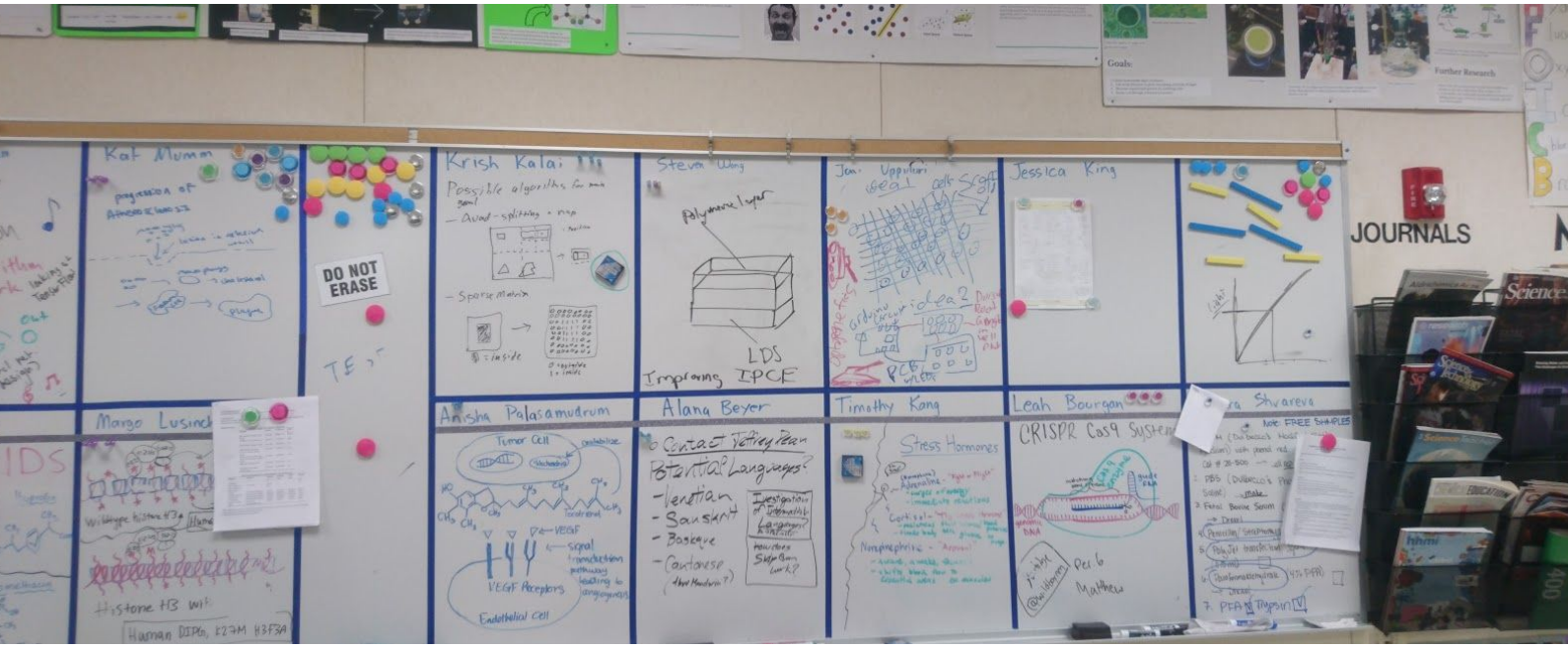
In biotechnology class, lab experiments have been designed based on recent research work in the literature, including those that students themselves have identified. Biotech teacher Meghan Strazicich discussed a paper[26] about the effects of pesticides on the insect population with a student in her class, found some interesting results and contacted the authors. From this she has developed some experiments that will add to the dataset. This is relevant as the effect on the insect eyes requires an SEM to image. Another example was the effect of antioxidants on the behaviour of model organisms, in this case microscopic worms. The students themselves designed the experimental method and the results of the whole class were collated. This was especially

interesting as there is an ongoing debate in the department about how best to encourage and teach better data analysis and statistical methods. Acquiring class-sets of data for experiments has been the first step so that students are working as a large group and thinking about contributing to the body of data. This is real research embedded within 'regular' classes.



The robotics workshop, note sponsorship for the 'First robotics' competition from; Google, Lockheed Martin, Hewlett Packard...etc.

An additional and unexpected feature of this school was the design of the buildings due to the beautiful climate of the bay area. Corridors don't exist as outside space is your corridor, all classrooms have an external door. The internal corridor of the science department is a giant preparation laboratory, an Aladdin's cave of equipment and space. Teachers are able to discuss and collaborate effectively as they pass between classes. Resources are shared and teachers are always near to equipment they need. This is Mountain View, Ca, one of the most expensive places in the world to live. The school's real estate is used effectively and the campus has an open feel. Classrooms again follow the research theme, whether by accident or design the lab space is the key element with the 'chalk and talk' space fitting into the remaining area. This gives the impression that the lab work is essential and not just an added extra.



The projects board in the lab where research classes are held. Note the selection of scientific journals. The choice of projects was incredibly varied, all experimental.

Recommendations:

- Increase the provision and resources for curriculum use of the research tools. A good start has been made by many organisations including Pfizer's community lab or the Royal Microscopical Society's class set of microscopes but many science teachers have a barrier to engagement due to lack of training (or indeed, time).
- The model of bidding for the parent's group funding is interesting. Greg Stoehr, on his recent visit, cited the fact that not all teachers or departments bid and he felt that those who had a genuine case were successful in their applications. There is money available in the UK beyond individual schools especially for the maintained sector. If there is a community or charitable link then organisations such as Livery companies are keen to help.
- While there are not as many opportunities, the sources of funding for sustainable projects like the robotics course at Los Altos from local businesses would be a useful additional strand to any school science project. This certainly does happen but I was amazed throughout the trip as to the extent companies are willing to put money into local schools. There was certainly a local theme where companies are looking ahead to the future workforce in and around where their factory or laboratory is based.
- The design of the laboratories and the shared preparation space was incredibly interesting. With much rebuilding in schools and many different philosophies present it is clear that a school wishing to pursue IRPs and has the opportunity to rebuild laboratory space should look to what has been designed in US schools such as PRISMS, Los Altos and BCA.

Challenges:

- For a classroom teacher or department chair to be chasing funding they require time. In fact funding may include cost of cover for a teacher and thus provide time. Again, collaboration can help especially if private-maintained links can be developed where time/money resources may be available in the private sector to team up with a state school wishing to undertake IRPs or facilitate research.

Aptos High School & Foothill College/Palo Alto HS

Aptos and Palo Alto high schools are very different yet they share an approach to research and access to research techniques/equipment due to the influence of external providers. Aptos is an agricultural area in Monterey bay with a higher proportion of free school meals and certainly a lower school district spend on science (approx. $10 per year per student for standard science classes). Palo Alto HS, directly across the road from Stanford University and in the very heart of Silicon Valley. A rich neighbourhood with the benefit of a school district attracting funding from high property taxes and the added injection of funding from a very active parents group. While not comparable from a resource point of view, in both schools there is input from external agencies that really enhance the science provision, specifically enabling use of science research equipment and teaching research skills.

A hammerhead shark at the incredible (and famous) Monterey Bay aquarium.

Greg McBride, head of science at Aptos, has been running a research class in association with Monterey bay aquarium for the last few years. Monterey Bay aquarium is a private research endeavour for marine science with the public face of a fantastic aquarium open to the public. The two bodies (research arm and public aquarium) are separate entities and had significant funding from the Packard foundation. Part of this is a dedication to STEM education at school including the WATCH[27] project which involves schools in the Watsonville district and provides an elective science research class, two week summer training camp and opportunity to work with the Monterey bay aquarium on research projects.

Students apply to take the class which is limited in numbers since significant funds come from the foundation and the school district together, aiming for 35 fully funded places. This transforms the opportunity for those students on the course as the nominal funding for the year comes in at around $7000 per student. This includes everything the students need; transport to the research sites, food, the two week camp plus money for equipment and consumables for the entire year. This is charitable money to help out schools outside in relatively poorer areas and some of the students that gain from the course can't even swim, despite the school being almost next to the Pacific coast (an example of the poor student that is not participating in the normal life of teenagers in the area because as a result of their family circumstances). Aptos is in an unfortunate situation as it does not have enough free school meal students to gain extra state funding but enough that require extra support which therefore takes resources from other areas of the school. A similar challenge for many state schools in the UK.

Tracking outcomes is important (as ever) but the program is only in the first few years, so it is too early to know whether there is a statistically viable affect on outcomes. The was the usual raft of anecdotes some particularly poignant including the student who literally did not speak in the presence of others who took part in the course (notably the summer training camp) and is apparently now at grad school studying law!

The students are allocated a mentor, usually a postgrad student from a local marine biology or oceanography department and they develop a question based on a literature survey of their chosen area of interest. The key thing is that they are able to go to the various wetland habitats which are under scientific interest or owned by universities etc. This is often brand new research. Ultimately the groups will present their findings at a gala event at the aquarium where they will give a talk and defend a poster to the general public and invited scientific community. For many of them their personal development is huge. Talking to some of the students in the class I was struck by the level of self-motivation and determination they had to make a success of the class. They realised the value and the opportunity and were keen to make a success of it.

Greg McBride was very proud of the quality of work from all of his students, especially those from particularly disadvantaged backgrounds. He was keen to show me the conference posters from previous years.

- An example of the challenge of participation is the St Paul's 'Magic of Materials' summer school. This course is an intense residential academic course for students from state schools. The Institute of Materials Minerals and Mining help secure funding to make it accessible to as many students as possible including funding travel bursaries. However, there still appears to be a barrier to participation. Aptos are able to engage their disadvantaged students in applying for the WATCH program yet it seems that many students from disadvantaged backgrounds find even the train journey into London a barrier to applying to be part of the course. More local opportunities and well-resourced schools providing a base for such opportunities may help to widen participation.

World's longest model nanotube (apparently made especially for my visit)

At Palo Alto the students are being given a different opportunity but no less enhancing of their resumes. Foothill college is a community college on the outskirts of Los Altos, Ca, which has a beautiful campus and terrific STEM college courses. I visited a nanotechnology class, run by Dr Robert Cormia, of Foothill College, Los Altos[28].

Dr Cormia is a college professor who just happens to be running a college level nanotechnology course in a high school. His background is in materials characterisation (in industry) and firmly believes the importance of characterisation as a pillar of nanotechnology/nanoscience research. He is awash with anecdotes about his time in industry and how businesses or government labs solved multi-million dollar problems when they [eventually] went to the microscopist to try to understand why their projects were going wrong. The nanoscience course at Palo Alto is an elective, not a core course, but is eligible for college credit. There are plenty of benefits for the students like the college credit, the variety of science they experience and the lab techniques that they can add to their resume. However, what I witnessed during my visit was the exposure to absolutely state of the art ideas and what Robert himself calls the 'grand challenges,' all of which are in some way related to energy and the environment. This may be through business efficiency and efficacy of products or simply "*technology that might save the world"* (biosynthesis, solar photovoltaics, battery technology etc. etc.)

During my visit they were looking at sustainable, cheap, easy to produce brand new photovoltaic cells that could be rolled out quickly in areas of need such as refugee camps. The students were measuring efficiency which brought together maths and physics as well as a discussion about the polymer chemistry of the cells themselves.

As part of the course the students gain access to Foothill college labs where there is a scanning electron microscope (Hitachi TM3000) and table top Atomic Force Microscope (Pacific Nanotechnology). Through connections at NASA and other academic institutions Dr Cormia is able to access further characterisation techniques when needed so he is ultimately flexible when a student wishes to run their own research project. I was incredibly impressed with the tech labs at Foothill including the 3D printing and mechanical testing.

Pacific instruments atomic force microscope, part of the bank of 3D printers and a mechanical testing rig all at Foothill College. Visiting nanoscience students from Palo Alto are able to use these facilities as part of their high school course.

The funding and the impetus comes from the external provider. In this case Foothill is keen to be part of the community and attract its own students from the local area. Palo Alto is a feeder school for the college so the partnership makes sense. The college system is very different in the US with a requirement for general education courses so often community college is a good option to reduce the overall cost of college for the first couple of years before majoring at a different institution. While the drive for quality, rigour (after all it is a college course) and content comes from Foothill, the students at Palo Alto are discerning in their choice of classes as they have to have a quality transcript and demonstrate their aptitude for college. This symbiotic relationship between the school and college seems a very sensible option although the question remains whether it could exist outside a region like Silicon Valley where expertise and innovation funding (even for education projects) appears commonplace.

The cheap and quickly deployable photovoltaic cell. A familiar sight, the TM3000 SEM at Foothill college

- Both schools demonstrate the benefit of partnering with an organisation, especially one involved with research. Both partners valued the interaction and the mutual benefit is clear.
- Once again deep impact outreach is in play, as well as offering 'taster' sessions or public engagement demonstrations a culture of bringing school students into research groups for extended periods of work experience or partnering on a specific project would be hugely beneficial to any institution. The USA values the deep impact outreach/engagement whereas UK public engagement seems to be measured mainly on the basis of footfall.

Challenges:

- All the schools that I've visited, from the richest in Los Altos/Washington DC to the low income inner city Bronx, they all seem to have superb sports facilities including the 'branded' football field – often high quality artificial multi-use surface. Yet the spending per student or the staff salaries are wildly different. It wouldn't be fair not to throw out the question of priorities, especially in areas that are struggling to fund even the most basic chemistry lab equipment. I understand the importance of school sport in the US, and the pride and sense of identity it brings, but there has to be more to it. Many science teachers were unhappy about the balance of funding.
- Having attempted to build collaborations with universities I've had mixed success partly due to the safeguarding or health and safety considerations when working with U18s. While this was a consideration at Foothill, policies are in place and high school students are appropriately supervised. In many discussions there is a barrier (due to the assumed paperwork or logistics, or simply taking time out of their research) to lab managers and group leaders taking on students.

Otto von Taube Gymnasium

Chemistry and geography teacher Steffi Meincke welcomed me to Munich for the final leg of my travels courtesy of the WCMT. Otto-von-Taube-Gymnasium was not originally on my list of schools to visit, however, meeting Steffi at the St Paul's International student science conference was proof of how networks and events can lead to unexpected outcomes. Celebrating its 50th anniversary this year, it is an outward looking and innovative school with an incredibly friendly student and staff body.

Around ten years ago the Technical University of Munich (TUM) decided that it wanted to have an impact on secondary education to boost recruitment to STEM courses and possibly to set up its own high school. After a couple of years of discussion and various iterations of the project it settled, in 2009, on a scholarship program where students apply to become TUM scholars for their final two years of high school. Becoming a TUM scholar is competitive and requires completion of an application form, interviews and teacher references, however the rewards are remarkable and there is certainly a good deal of jealousy amongst the remaining student body, not least because the TUM scholars miss school each Wednesday to undertake their research. The program lasts for around 18 months and finishes with enough time for students to catch up on revision before their final exams.

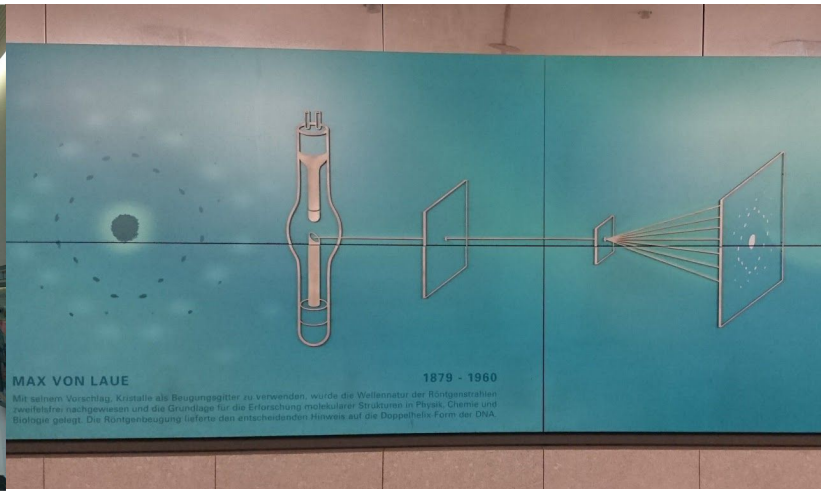
The collaboration has become very successful with a network of alumni where a number of previous participants are now becoming involved with mentoring students themselves. It has been particularly good for the school which has improved its standing in the community, while only 15 or so students can take part the prestige of the project draws students to apply to the school. The project has also been subject of a master's thesis and the administrators are very keen to track the outcomes of the participants.

Medical research labs at TUM

It starts in 10th grade (equivalent year 11 UK) where younger students attend a presentation and workshop delivered by the outgoing crop of TUM scholars (without any help from staff) . This provides a taste of the available projects or disciplines. After the selection process in the 10th grade successful candidates begin their training at the start of 11th grade. For the first few months they attend a rotation of visits on their Wednesday TUM day to the various research groups in the different departments of the university. In parallel they are given training in how to write letters of application and construct a cv. There are lessons on interview technique and they are expected to contact their group of choice and apply for a position as a research scholar.

The bulk of the program is the research, the scholars are embedded in a research group and work for a supervisor at TUM, this could be a lab manager, PhD student, PI or equivalent and the scholars are expected to manage their workload and plan their activities, in many cases this means working during their holidays or late at night on their TUM day.

They do not get less school work as their entire school week is squeezed into the remaining four days. There is no doubt that these scholars have to work hard but the rewards are fantastic. They work as a PhD student throughout their time, this is not pretend or simulation but real projects either instigated by the lab or developed by the students themselves. They have the opportunity for a three week study visit to another country (e.g. the Mini factory in Oxford and the university of Utah) and they present their findings at a gala research event at OvTG. Over the last few years the exchange with St Paul's school has seen a number of the TUM scholars present their work at the International student science conference. The key outcomes are enjoyment of the work, doing real research and using state of the art equipment, something that they absolutely do not get to do in school. It is a path changer for some, the tracking of alumni is beginning to tell a story of real success in STEM careers.

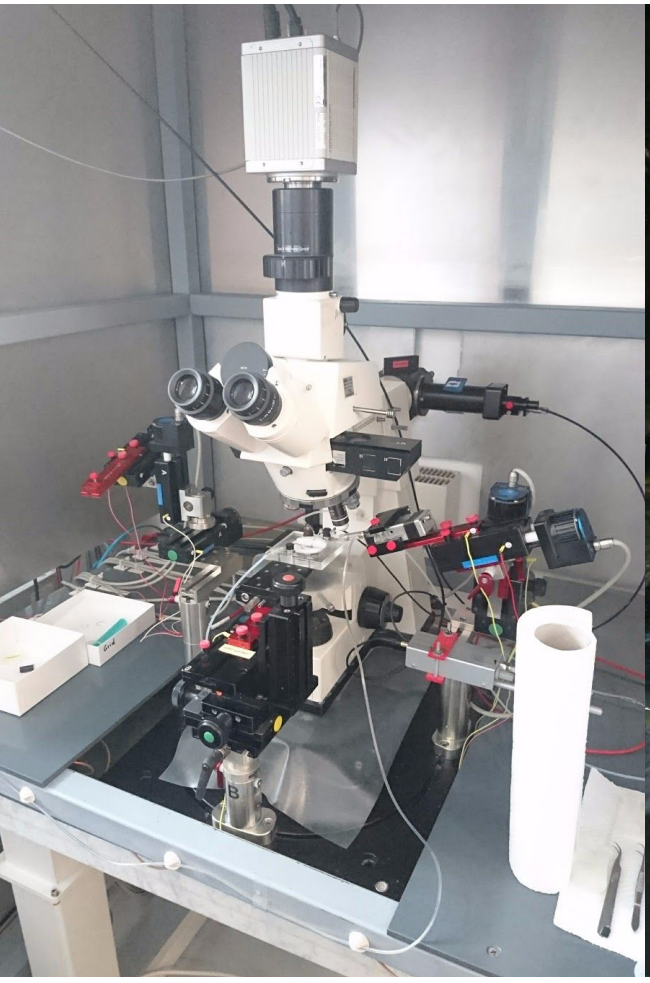


The famous parabolic slide in the TUM maths building. Electron diffraction explained (in the TUM campus tube station)

The TUM scholars are expected to present their work in English as well! This is because the university is moving towards full teaching in English and recognises that English is the language of most International science conferences. I spoke at length to two of the scholars; Kaspar Winter and Nicholas Leister, both were fluent as far as I was concerned with just the occasional obscure physics term missing from their vocabulary. Very impressive indeed.

Kaspar's project is unusual in that he is gathering data and generating simulations for traffic management in Munich city centre. This is essentially a data science project where data has been collected about drivers response to signalling and cyclists behaviour at intersections. Some intriguing findings have already been discovered, for example how cyclists will chose an optimum route between shared pedestrian and road sections depending on how the traffic signals change. Driver age is also an important variable that affects how they respond to cyclists at intersections. I'm looking forward to hearing if Kaspar solves Munich's congestion issues with a clever sequence of lights, thus saving time, improving air quality through efficient driving and maybe stopping a few incidents of road rage!

Nicholas talked eloquently about his work preparing,conducting and analysing neutron scattering experiments at the TUM beamline. He is lucky enough to be handling alien objects! Meteorites from asteroids, Mars, the moon etc. are being studied by a technique that can detect trace elements to better than 1/10th of a part per billion!




More microscopy (this time of brain slices - rats that is…) Physics on show with the river Isar surf spot, very polite queuing for their turn on the wave!

It has been a real pleasure to visit both the school and the various university departments at TUM that are hosting the TUM scholars. The model is surely one that any university could try. Dr Jutta Moehringer, once a teacher and now TUM administrator for the program from the TUM school of education, says that the main challenge is finding willing supervisors, not for the money but the time required each Wednesday and beyond. The scholars are still high school pupils and therefore cannot be in the labs unsupervised and there are health and safety considerations (and in some cases ethical - live animal experiments are not permitted for example, although brain protein analysis is) In terms of financial cost again it is time.

The school teachers at OvTG administering the program have to be out of school to make site visits every Wednesday, they also have a reduced timetable. This is a cost to the school but ultimately OvTG can apply for further teacher time from the Bavarian government due to the nature of school funding. A small number of TUM undergraduates are given a stipend for mentoring the scholars.

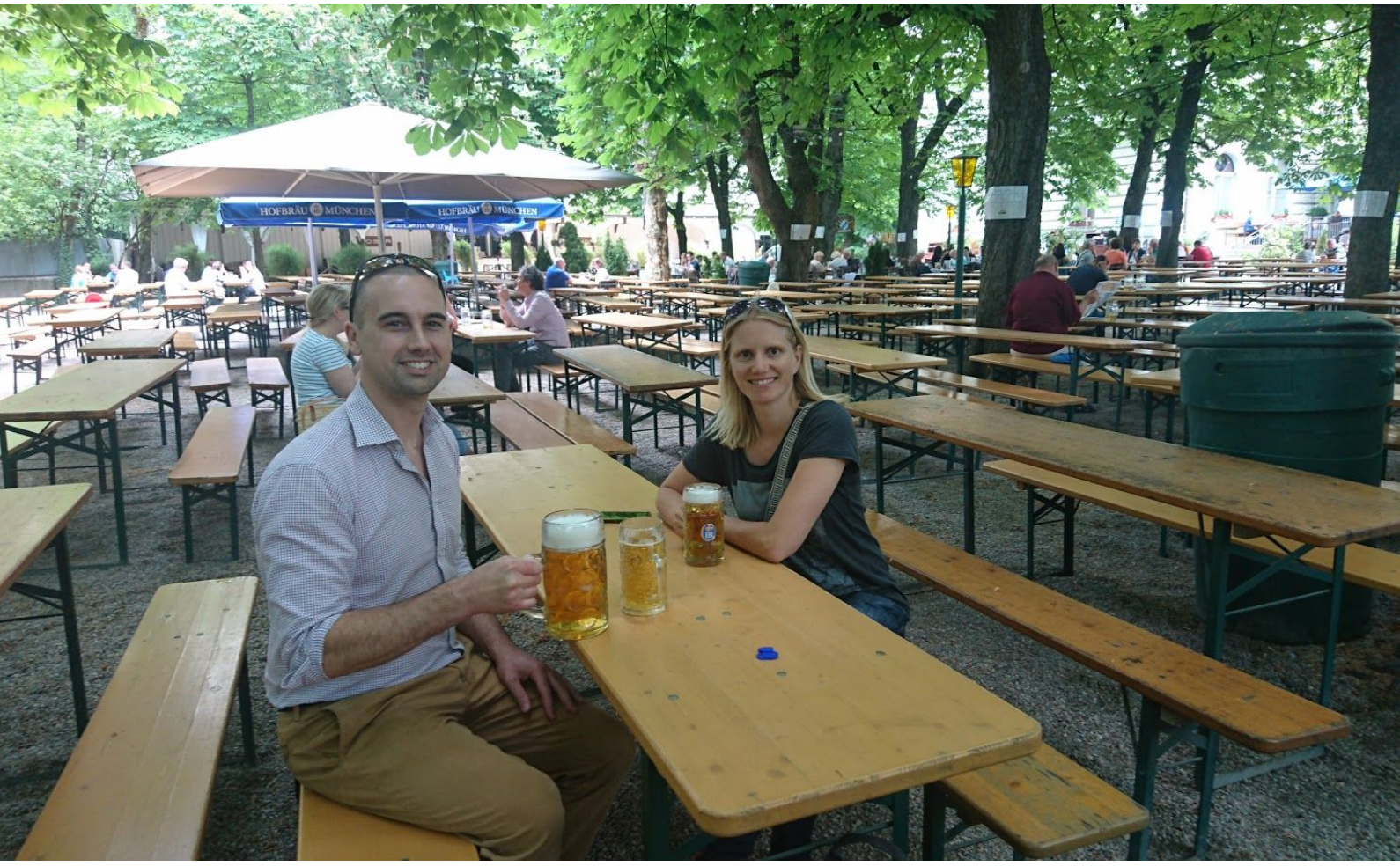
Dr Moehringer and I had much the same conversation about the benefits of such a program as I have had during many of my visits. The advantage here is that they are generating data about outcomes that goes beyond anecdote and after nearly ten years of the program there is no sign of it running out of steam, quite the opposite in fact as this year a second Munich school from the other side of the city has joined, doubling the number of participants.

Recommendations:

- Truly embedded research experience, with high school students using state of the art equipment and techniques with full support from school and the university. Might it be possible via a work experience program to have a competitively selected yearly opportunity for a number of students.
- Adjusting the timetable for a small group is challenging, but those involved with collaborative research projects with external schools or organisations may be put in a separate teaching block. A challenge for the timetabler but an opportunity to extend their experience beyond the school, possibly as a year long project in year 12 (that could ultimately be written up as an EPQ).
- Ensuring that there is a deliverable outcome, be it a poster, presentation, attending and/or presenting at a conference is essential. It does not necessarily require a publishable result but this gives a sense of timescale and a minimum 'cost' for the student to gain the experience.

Challenges:

- Internships and work experience have become politically difficult. However, by bringing partner schools into a collaboration and working with open minded external organisations there may be opportunities for such long term deep impact experiences.



Where better to discuss education with Steffi and Dr Moehringer than a beer garden.

A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty.

Summary of findings

In addition to the general recommendations from each visit I have summarised some further ideas and recommendations together in a number of broad categories.

Recognition from school leaders

- In many cases the leadership of the schools did not have a science background and the scientists were viewed as 'doing their thing, over in science'. My hosts said that excellent work with major outcomes was not given credit, publicity or taken as seriously as other programs simply because of a lack of understanding of the science and the context. School leaders must engage, often the students will be able to communicate eloquently themselves about activities within a department.

Faculty expertise

- Linda Rosen's description of the 'alpha teacher' could be applied to most of the teachers I met at the various schools. Mike Boyer and Dave Menshew's commitment to education through research during their own summer holidays, Greg Stoehr's success in funding applications, the career change from academia or business to teaching of David Hauser, Darren Dressen, David Reeves etc.
- This is mirrored in many parts of the UK but as budgets are stretched, those with more experience cost more to hire. Attracting good people from a variety of backgrounds was common to all the schools visited. Use of external mentors is helpful for specific research classes, something to consider for the EPQ. The value of the experience and background of staff was a clear theme.

Structure of school day/timetabled time

- The variety of timetables was interesting, although not unusual. The case for changing the timetable and structure *specifically* to facilitate an active research program was well made. BCA have gone beyond this with their Wednesday projects which is over and above the research classes. BCA also have the system of academies which takes the student through the training to do a project and then gives lots of time, resources and expertise (staff) to guide them through.
- PRISMS also bases its entire curriculum around supporting the laboratory research. They have removed competitive sport (unusual in America and rather extreme!) and developed focused cross curricular activities in the humanities and arts subjects so that the students understand the context of their work and how the other subjects complement their research.
- The differences in US high schools make setting up a research class easier in many ways. Once approved by the school district they can timetable a class each day (most of the classes were 90 minutes every day or four out of five days for a year or two of three terms.) This is well beyond the current EPQ allocation and the outcomes reflect this.
- The time requirement of teachers is recognised and/or a point of conflict. BCA teachers either have a shortened timetable for regular classes to be a research mentor or choose to be a regular teacher without any research classes. No question of having a full timetable then adding mentoring or treating it as extra-curricular. PRISMS have lab directors who are dedicated to research classes. Otto Von Taube teachers who are supporting the TUM Kolleg have a reduced timetable to reflect the need to visit students (and the travel it requires) each Wednesday.
- Time was most commonly mentioned challenge at every school I visited. Less so when the school day was managed in such a way to allow appropriate time both for the students to do the work and for the teachers to support - including time for writing grant applications, adequately mentoring and supporting research students or troubleshooting equipment issues.

Partnerships and networking

- The true benefit of networking and partnerships was recognised by the schools that had the most successful program. As seen by the TUM Kolleg program, it becomes self-sustaining with alumni of the course now taking on students in their lab.
- The mentoring from external people was common to many schools and in most cases it was driven by the students themselves who contacted appropriate people in the field.
- External organisations and businesses saw the value in experience, internships and partnerships. The corporate social responsibility aspect seemed much more prevalent and led to terrific opportunities for students, for example designing new experiments at the BioBASE, or working at the USDA for a year.

Anecdotes and tracking

- Tracking the outcomes of students was something universally desired but understood to be incredibly difficult. Change the Equation's approach of following the entire career with detailed transcripts will generate excellent data but may not be practical (or legal?) in all cases.
- Los Altos' Meghan Strazicich use of linkedin is generating interesting data but cannot determine whether there are any pathway changes due to a specific intervention.
- It was widely accepted that anecdote is important in light of a lack of data. Put into context the anecdote of a success story is important. Moreover it is the anecdote that may be inspiring other students to take a similar path.
- The discussions with top US colleges that schools are having (plus the growing data from the schools regarding acceptance rates) 'suggests' that the colleges are keen to accept students with IRP experience. Specifically BCA notes that MIT is accelerating BCA alumni through laboratory classes due to their experience. There are also a number of schools where the research program gives them college credits towards their general college education. This appeared to be a key driver for many students.
- Schools that offer enhanced experiences for students must think about gathering information about which students are actively engaged. Is it a sub-set of the school community who are engaging with several opportunities or are the opportunities shared out amongst the whole population. The self-selection, especially in science and engineering may lead to some missing out on beneficial experiences because they don't feel able or willing to be involved in the first place.

Outreach & partnerships

- It is important to maintain and foster partnerships especially as an equal partner, for example where St Paul's have the facilities for using the SEM and other schools have experiments which require the collaboration. This allows the students to collaborate and is not seen as an 'outreach event' i.e. where a private school is 'gifting' time/resources to a good cause. Partnerships work with demonstration events such as 'science uncovered' or Wonder.[29,30] A great opportunity for those taking part to meet the public and/or schoolchildren from other schools.
- Hitachi are looking to expand their program of STEM outreach into UK and Europe.[31,32] Organisations linked to IRPs such as IRIS can provide a readily available network for companies like Hitachi to tap in to where there are willing schools and students looking for opportunities to use the equipment.

Long term loan model

- After witnessing the effectiveness of having the SEM in place for a longer period (for example at North Penn and James Enochs) a model of loaning advanced instrumentation seems to tick many boxes. Access to research equipment for IRPs but also the community, engagement and curriculum enrichment where regular lessons can be adjusted more easily over a longer timescale.
- The long term model allows for deeper impact outreach, for example by facilitating work on a specific EPQ of or allowing a class to follow a course of lessons where each uses advanced equipment for an extended period rather than a showcase event. This does depend on whether the equipment is transportable and if appropriate logistics are manageable.
- Hub facilities. Either within a school or within a suitable institution (e.g. the National network of museums linked to the Natural History Museum) loaning or group purchasing equipment to be available in any given local area for use with long term projects would be suitable as long as students can access at appropriate times.

Outcomes

Dissemination of findings

I have been blogging about my various visits on the IRIS webpages,[33] indeed further details about the visits can be found on the blog as well as comments about my experiences visiting the various organisations. This blog is public and has attracted a number of communications. Each post was fact-checked with the relevant organisation prior to publication.

St Paul's news and the St Paul's website has featured regular updates of my travels, again leading to interesting networking opportunities and conversations. I have presented a summary of my findings to the school's Halley Research Community (HRC) and discussed my travels at the inaugural 'common room conversations' event for all staff at St Paul's. This report will be available on my page of the WCMT website.

I have been taking the opportunity at every turn to talk about my travels and findings, most recently for the WCMT South East Network in September 2017 and for the Whitstable branch of the ex-round table association; 41 club in January 2018. I also had a meeting with Sir Julian Brazier just before he lost his seat. He was keen to hear more and will receive an executive summary of this report in due course.

TES awards

My travels on behalf of the WCMT and the subsequent influence on the science conference, research in schools and our increasing profile both Nationally and Internationally indirectly led to St Paul's science and engineering departments being nominated for the team of the year at the 2017 awards. Collaborative research and outreach events involving the electron microscope were at the heart of the nomination and proves that the ambitions of the project fit with many people's ideas of what good education can be. True collaboration between sectors with positive outcomes for all parties; for example use of SEM by Simon Langton school over the course of a number of visits involved training by St Paul's boys, collaborative data and image analysis, submission of EPQ by external school student acknowledging St Paul's and topped off by a competition winning presentation at a professional science event.

International science conference

The St Paul's School International Science Conference was bigger than ever in 2017 thanks to contingents from schools that I had visited during the Autumn term. Matthew Pearce, principal of PRISMS made a special visit to discuss potential research collaboration and get a sense of the scale of the conference. North Penn high school's Mike Boyer managed an incredible feat of crowdfunding to visit the UK. Three groups from his research class presented their work at the conference, one group going away with a prize for best talk. Their feedback has been outstanding and they are very keen to collaborate with UK schools in the future. We had representatives from Japan and Germany as before, but added Belgium to the growing list of European countries involved, on the back of the Svalbard long duration weather balloon trip.

There have been offers from the university of Birmingham to facilitate a further expansion of the conference and offers from organisations such as researchers in schools to further develop ideas of collaboration and science research in schools.

Simon Langton School long term loan trial

By taking the model of North Penn HS and James Enochs HS, I arranged a three week loan during the crossover week and Easter Holidays while St Paul's school started Easter break and Simon Langton were still at school. See appendix for summary report on the trial.

Royal Microscopical Society

Networking opportunities that have come out of the sabbatical through publicity or contacts made have led to my being elected to the education and outreach committee of the Royal Microscopical Society. Through the RMS, the SEM been invited to be part of a number of events. The first of which was 'wonder' at Nottingham university, an outreach event involving the many research groups and departments showcasing their science. Two boys and two members of staff took the SPS SEM up for a day of exposition led by the boys themselves.

We are now in discussion regarding a teacher CPD training day that can be offered to train teachers on advanced microscope techniques with the aim of being able to support IRPs and enrichment. This will encourage use of the RMS secondary schools optical microscope which has additional features over and above the normal 'school' level optical microscope. In addition they will receive training and ideas about how to incorporate electron microscopy into lessons and IRPs.

Hitachi support for the outreach program

Bob Gordon and Lori Harvey at Hitachi are keen to work on developing outreach and enrichment projects on a longer term basis to help develop their outreach program in the UK, including testing resources and supporting electron microscope visits. Mike Dixon, the UK representative is keen to maintain the excellent relationship we have with the company where we have been able to support outreach events that Hitachi do not have the personnel for currently. In exchange they can support us when we need technical support, and will always provide on-site technical support over and above our service contract.

For companies that manufacture advanced scientific instrumentation there is not only a burgeoning market within the UK secondary education sector but an appetite from both students and teachers to access such equipment. It requires the manufacturers and educators to meet in the middle with the manufacturer providing equipment and the teachers helping to develop projects and curriculum materials.

Most often in the basement…

EPQ in science research

Early on in the visit it became clear that time was absolutely key but also the motivation of students and parents was often at odds with the motivation of staff and mentors. With longer term research projects many students in UK schools will do them just for fun, but this limits the amount of time and money available for those activities. In a wider context, state schools may struggle to facilitate any long term 'hobby' projects at all, thus removing the opportunity entirely. By its nature science research, unless specifically dealing with data science, requires some lab space and access to equipment. The EPQ is a perfect opportunity to solve some of those challenges by providing a well defined outcome and deliverable for the research but also allows it to slot into regular school timetable. As proved by BCA, Los Altos, North Penn etc. if the research program is an official option then the parents feel like there is benefit yet all of the benefits of a long term independent research project may be realised.

The EPQ is a fantastic opportunity to do an independent research project fully supported by the school. While the time allocation doesn't compare with the USA schools, it sits well within the constraints of the UK system. EPQs can be further enhanced by looking for external mentors to support science research projects either for use of external equipment/data gathering or simply to be that expert contact to help guide the student through the process.

St Paul's physics inset event

The external physics teacher inset event was in two parts this year; firstly 'going linear' and secondly a characterisation hub training session. Feedback has been good and we have discussed two collaborations with visiting representatives, including helping to refurbish an x-ray diffraction machine. The physics inset had a strong research and project theme including the discussion of how a 'mini EPQ' was introduced to our linear physics scheme of work, something very much of interest to the delegates. Further collaborations are expected as an outcome of this inset.

Los Altos school visit

Three members of the Los Altos HS science faculty visited the UK on the back of my visit to their school. Destinations included St Paul's, Simon Langton Grammar School for Boys and Eastbury Community School during the first half of the summer term. They spent time meeting with members of staff and observing lessons. The sharing of practice and study of different educational cultures was as valuable to them as it was to me during my time at Los Altos and it was a pleasure to be able to facilitate their visit. Amongst other things they discussed laboratory experiments, science instruction, use of ICT in the classroom and beyond, research in school and mental health and wellbeing.

Queen Elizabeth Grammar, Faversham

Since being awarded the fellowship and undertaking my travels I have taken up post of head of science faculty at Queen Elizabeth's Grammar School, Faversham. As a member of St Paul's Science department I had already worked with schools in that area including Simon Langton Grammar and King's Canterbury and these collaborations will continue with the addition of QEGS. There has been some mention of the 'new inner cities' being the coastal seaside towns, QEGS fits firmly in this remit with a very mixed demographic and typical challenges facing a maintained school.

The new senior STEM club "QuEST" has already made contact with North Penn HS and will be running a collaborative project on nanotechnology this year. I am actively engaged in discussions about other collaborative research projects and have received funding for equipment from the worshipful company of armourers and braziers to help with this endeavour.

Developing global network

A terrific outcome both from the visits and from the International Student Science conference was the willingness and enthusiasm to introduce students to International collaboration. Ambitious ideas have been discussed but it is one area that can genuinely start small, simply by discussion. This is important on many levels as a global network is developed to foster both good practice in education and train students for the modern global workplace.

A number of schools that were visited during my travels were very similar in many ways. This was not surprising given the activities that I was visiting, the need for expertise and resources meant that the projects really happened where there was a good source of funding (affluent areas or access to state resources) and in many cases where there was a quality higher education or research institute nearby. This means that there are a number of activities that the schools have in common, for example looking to research programs or IRPs to enhance and enrich students experience, applications to International universities, a well resourced and thriving extra-curricular program in sports, music and the arts.

Yet another common theme was to continue the dialogue beyond the National borders, this is something that science is so good at encouraging.

The Winston Churchill Memorial Trust Fellowship

I was travelling as a 2016 fellow of the Winston Churchill Memorial Trust www.wcmt.org.uk. The organisation's strapline is Travel to learn, return to inspire. This was my mantra throughout and aside from the funding the trust was a terrific source of information about how to get the most out of travelling, where to develop networks and importantly I have met a fantastic network of 2016 fellows. We all kept in touch and made sure that we let each other know of interesting places to visit. One of my discoveries, Bergen County Academies, has already featured in the report by Rosie Clayton, another 2016 fellow.

I believe the process of applying and being interviewed for the fellowship helped crystallise my ideas and gave me real focus for my visits. The dissemination of findings is a key part of the fellowship and with this in mind it maintains focus and helps to ensure that the information does not simply remain in the brain of the traveller. It also opens doors. I have already had a meeting with Sir Julian Brazier to discuss education and have been invited to talk about my travels by the Worshipful Company of Armourers and Braziers at their next alumni meeting. Churchill crowns (old coinage commemorating the death of Winston Churchill) have been gratefully received as gifts by the host schools and individuals helping to cement the connection between our schools.

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Appendix

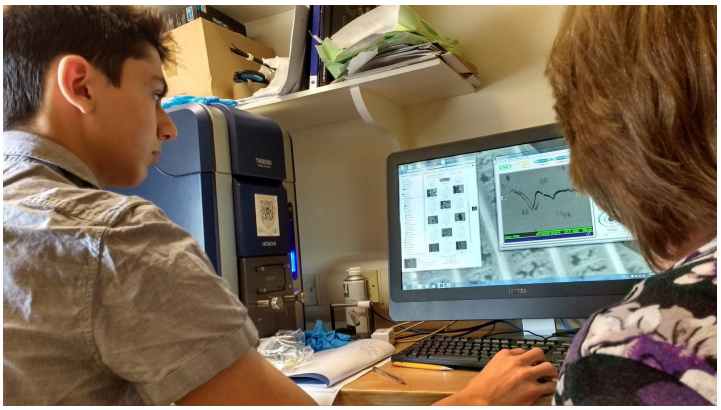
Appendix i - SEM Long term loan trial report

St Paul's School / IRIS characterisation HUB / Hitachi UK outreach program

Long term loan of SEM trial April 2017

Dr J M Perkins[1], Dr Barbara Kirby[2],

1. St Paul's School, Lonsdale road, Barnes, London SW139JT
2. Simon Langton Grammar School for Boys, Nackington Road, Canterbury, Kent, CT4 7AS



Ilya Carey, student lead user at SLBS

Motivation

The trial objective was to improve on the experience using the SEM for schools with existing collaborations/projects/links with St Paul's/Hitachi by introducing a new scheme, a *long term loan.*

"Long term loan"

1. It is expected that a loan will be between one and six weeks (depending on time of year and project/experiments/number of samples)
2. A long term loan will require a member of staff on site to be fully trained (staff training to be defined as: familiar with all modes of use - imaging modes, EDS, tilt-rotate stage, sample preparation and loading - it would not normally include filament change or troubleshooting).
3. Further support may be from St Paul's staff or Hitachi depending on geographical location, support needed and staff availability (e.g. for a filament change or further training) and may be online e.g. via Skype.
4. The model is based on the loan of a TM3030 to James Enochs HS and North Penn HS in the USA where there is a *specific need* for a long term loan as part of an ongoing research projects and/or part of the curriculum.
5. The trial is in expectation of a TM3030 with EDS being available to schools in the London/South East region (as a starting point) *in addition* to the SPS owned TM3030.

As opposed to; *"Short term loan*"

1. Defined as an event where local training is NOT required.
2. Operation and on-site support by SPS or trained users (possibly those involved with long term loans or other collaborative work or Hitachi representative).
3. Single day outreach event e.g. Science uncovered at the Natural History Museum, "Wonder" at the University of Nottingham etc.

The current model for *collaborations* with St Paul's and use of the electron microscope requires that participating schools (or individual students) are able to travel to SPS for a day so that the students are able to be trained (usually by a member of the Halley Research Community). Subsequent visits should normally include some discussions with members of the HRC about the work and regular updates about how the work has been used and/or the deliverables produced. Examples include posters/presentations at conferences (with appropriate acknowledgement or co-authorship with St Paul's - including both students and staff), reports/qualification (for example EPQ projects) and articles (papers published in journals, articles in the press).

If a school or group requires more time on the instrument then it may be feasible to arrange a long-term loan. Two research groups at Simon Langton Grammar School for Boys used the SPS SEM during the end of spring term and over the Easter holidays (including crossover time when SPS were on holiday but SLBS were still at school). The structural colour group led by Barbara Kirby used the instrument to gather vital data for an EPQ project (Ilya Carey), and the polymer science group led by Dr Nicola Robinson (Head of Science at SLBS) gathered images of macroporous polymer structures for solvent absorption.

Logistics

JMP made the usual checks with the SPS insurers for an external visit. Overnight loans require that the room in which the microscope will be used is lockable and alarmed. In this trial JMP picked up the microscope in his own vehicle, unpacked and set up in the lab and conducted a training update with Dr Barbara Kirby and student lead, Ilya Carey. JMP lives in the area and so was able to provide tech support if needed. In this instance, only advice over phone/text was used.

Experiments

As well as the two research experiments, the SEM was demonstrated to a number of regular classes. It is expected that this *should* happen during any long-term loan. The collaborative nature of the long-term loan was enhanced by virtue of the fact that student members of the teams from SPS and SLBS were able to discuss the work via skype during and after use of the SEM.

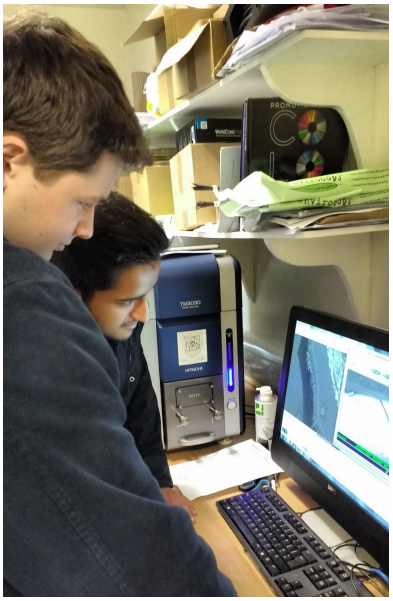
Skype collaboration between Ilya Carey (SLBS) and Umer Hasan (SPS)

Outcomes
The work will form part of an EPQ project as well as contribute to the ongoing collaboration between SPS and SLBS on the structural colour project. It is hoped that a new collaboration involving the macroporous polymer project can be initiated with further samples sent to SPS and additional users from SLBS becoming SEM-trained.

Further use by SLBS staff

A further 17 students were given the opportunity to attend a workshop that Dr Kirby ran explaining how the SEM worked. One of these students was able to then explain to Dr Robinson the science behind the instrument. We believe that this experience kindled further excitement about science and is likely to encourage individuals to pursue science at university and beyond.

Advantages of long-term loan.
With the particular challenges of the school day and timetables for staff and students, ensuring a 'high value' outcome from a single day visit is difficult. The model thus-far requires a training visit and follow up sessions which are often challenging to schedule and incur costs to the visiting school. With a long term loan out-of-class sessions (before school, at lunch, after school, weekends, holidays etc.) can be used and the users become much more familiar with the SEM (deeper science experience).



TM3030 use by other students at SLBS during the loan period.

Potential challenges

Technical support may be a challenge depending on date and location. Having an instrument away from the characterisation HUB restricts the activities at SPS. It is anticipated that the number of long-term loans will therefore be limited. The level of training of the users needs to be higher than that of visiting users although this will inevitably be true due to the collaborative nature of long-term loans in the first instance. Ensuring appropriate outcomes is difficult - a standard set of guidelines should be written to provide explicit instructions and exemplar press release. The minimum will be a project summary (with photos and example data) for SPS and Hitachi records. Transport is potentially an issue - requirement for full set-up on site with recap/enhanced training of users means that either an SPS or Hitachi expert would need to be present for set-up and also to collect the instrument to pack it away.

Cost may be an issue in the future, both the cost of transport, additional insurance and staffing for support (if needed). However, with more trained users and with further advanced or basic support training from Hitachi FOR teachers, this could be solved at the same time as generating a network of experienced users to support each other across the region.

Summary

The trial was a great success with multiple trained users and contributions to two separate research projects. Additional engagement opportunities with other students was taken up and deeper links between the schools, and indeed between students at the two schools has developed. Due to the geographical location (JMP & SLBS!) the technical support and transport logistics were straightforward however a sustainable funding model to cover expenses needs to be developed. An amended service contract reflecting the outreach and engagement activities in partnership with Hitachi should be discussed.

The opportunity to host a second TM3030 with EDS in the London/South East region for a number of short and long term loan events would produce some valuable deep-impact outcomes as well as potential for larger scale engagement opportunities. There are a growing number of expert users who may be able to support the activities, however input from Hitachi would be essential to ensure the success of numerous long term loan events.

Appendix ii - Travel and Itinerary

Much of the travel was arranged with the help of Richard Latham of Zeta tours who regularly arranges travel for St Paul's school trips. I would certainly recommend his company for future sabbaticals. As the cost of the travel element was met by the WCMT which is a charity there was a requirement that travel be as economical as practicality allowed. Travelling with children is never going to be cheap, however, hiring a car and using airbnb as much as possible allowed costs to be minimised.

Cultural exchange

Having clear aims and a focus to my sabbatical provided the hook on which to hang some real cultural exchange. Staying with the boyer family, a high school teacher of similar grade and age, allowed me to see what it was like to work and live in the US. Many of the schools were similar in many ways to the schools I am most familiar with in the UK. Not entirely surprising given what I was researching; even the public schools were often in rich areas where rather than school fees the parents would be paying very high property taxes and contributing in a very considerable way towards the philanthropic income of the schools. On the other hand I am unlikely to be able to experience life/work in a place like the Bronx without a very structured visit, yet following up via my contacts allowed access in a very informal way to visit and experience 'warts and all.' In fact most of the schools allowed me fly on the wall status rather than rolling out the red carpet, a much more authentic experience.

The duration of the trip allowed multi-day visits and 'longer than holiday' time spent in certain regions, in addition we were very much off the tourist trail. Both of these factors added to the authenticity and cultural exchange aspect.

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