White Paper: Genomics Into Schools

Opportunities to develop in Auckland schools educational initiatives that explore genomics

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Executive Summary

There is a shortage of students pursuing science, technology, engineering and mathematics-based careers and an urgent need to increase scientific engagement of New Zealanders. Genomics is the branch of science concerned with the interaction and function of all genes in an organism, such as a human. Genomics is driven by disruptive technologies and looks likely to shape the lives of the next generation of New Zealanders. It is therefore important that current New Zealand adolescents, including Māori and Pacific students, be given the opportunity to explore and understand what genomics is about.

The Auckland Genomics Into Medicine Programme is directed toward the long-term goal of developing a high output network of researchers, clinicians and communities/patients focussed around evidence-based genomic medicine. The establishment of sustained educational partnerships in genomics between scientists and schools, to foster public understanding of genomics and the development of future health care professionals, is therefore essential if the Programme is to achieve its goals.

To determine the best use of resources available for genomic educational partnerships, current science partnerships with Auckland schools were identified through a symposium held at the University of Auckland's Faculty of Medical and Health Sciences (FMHS), on April 5th 2018. Aspects of 17 Auckland science partnerships that teachers found valuable are discussed in this document. Based on these existing partnerships, several points for consideration when generating new genomics partnerships emerged. Based on practical aspects of the New Zealand Curriculum (MoE, 2007) and overseas studies, partnerships focused on students from years 7-10 (ages 10-14) may be the most practical and valuable. Learning strategies that provide students with a strong sense of 'agency' and personal relevance will be the most effective. Learning strategies such as forensic science scenarios, compelling fantasy scenarios or scenarios that focus on human diseases and traits can be especially relevant and engaging but need care to avoid any risk of student/whānau disengagement. Learning strategies need to be based on scientist-teacher partnerships, not on scientist 'outreach' towards teachers, ideally with these partnerships generating teachers as independent genomic experts.

1. BACKGROUND

The need for engagement of primary and secondary school students in science.

Participation in the global 'knowledge economy' is critical to the vitality, welfare and economic progress of Aotearoa/New Zealand. There is a general appreciation by the government, and by New Zealanders, of the value of science and technology. Nevertheless, a perennial problem has been the shortage of students pursuing science, technology, engineering and mathematics (STEM)-based careers. Moreover, there is the broader need to increase scientific literacy of New Zealanders to ensure equitable participation in the complex decisions that will shape their lives (Gluckman, 2011).

As stated by Joyce and Parata, in the Ministry of Business, Innovation and Employment (MBIE) 2014 National Strategic Plan for Science and Society 'A Nation of Curious Minds', "*Developing a more publicly engaged science sector and a more scientifically engaged public is a collaborative and long-term process*". The MBIE report identified three principal action areas, each incorporating several specific actions. The following are especially relevant here:

- Build stronger links between science and technology educators, learners, technologists and scientists, in the classroom and in the community.
- Encourage young people into careers in science and technology.
- Encourage parents and whānau to engage with science.
- Build stronger links between the science and education sectors and science centres, museums and zoos.
- Support scientists to contribute to broader science education while advancing their work.

Genomics - a transformative technology that will shape society

The New Zealand Government's desire to foster STEM careers and engage the public in science is also manifest in the Auckland-based Genomics Into Medicine program funded by the University of Auckland's Strategic Research Initiative Fund (2017-2019), and in the NZ-wide Genomics Aotearoa program funded by the MBIE Strategic Science Investment Fund (Genomics Aotearoa). A common goal of both programs is to generate a high output network of researchers, clinicians and the community focussed around genomics, including evidence-based genomic medicine. To achieve this goal, we need to elevate the understanding of genomic contributions to health and disease in current and future doctors, nurses and allied health professionals, as well as teachers of science, health, social science and technologies. More broadly, we need to encourage young people to consider science and technology career paths, including those that might interface with genomics, and raise public awareness of the value of genomic information in healthcare and wellness initiatives.

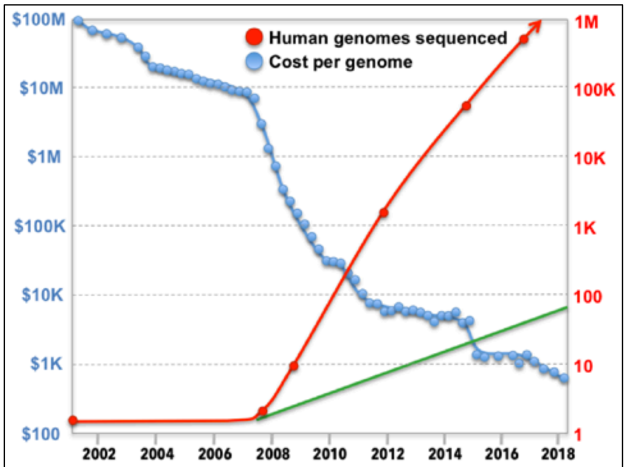

Figure 1. The Progression of Human Genome Sequencing.

The last decade has seen a 10,000-fold drop in the cost of sequencing and a 250,000-fold increase in the number of human genomes sequenced. In parallel, the time to assemble a genome sequence and identify important variants has dropped from 13 years to less than 48hrs (Farnaes *et al.*, 2018). As a benchmark of exponential technological change, Moore's law (a doubling of transistors on integrated circuits every two years) is shown in green. Adapted from Wetterstrand, 2018.

But what is genomics? Is it sufficiently important to require the attention of the public, who are inundated daily with new information, including that from other areas of science and technology? How quickly is this area moving and can we postpone thinking about it (**Fig. 1**)?

Here we define genomics as the science concerned with the interaction and function of all genes that make up the complete genome of an organism. This contrasts with genetics, which is the science concerned with heredity and how one or a few genes transmit characteristics, such as traits linked to health and disease, from one generation to the next. The science of genomics has rapidly expanded in the last 15 years due to disruptive technological advances. For example, new chemistries and DNA sequencing machine designs now allow hundreds of millions of DNA sequencing reactions to be carried out simultaneously.

The human genome, divided among 24 chromosomes, is comprised of three billion base-pairs (A-T or G-C) and contains approximately 20,000 different genes. The proteins these genes encode govern how every type of cell in the body develops and performs its allotted functions. Importantly, the majority of human traits (e.g. height, body type, brain volume, eye and hair colour, smoking behaviour) and diseases (e.g. cancer, heart disease, diabetes, autism, depression and neurodegenerative disease) are affected to varying degrees by many tens, if not hundreds, of genes. These genes interact with the environment, nutrition and microbial infection or colonisation (the microbiome). As individuals typically differ in their DNA sequence and 'epigenetic' modifications of DNA at several million base-pairs in the genome, a central challenge in genomics is to identify the variations in DNA that contribute to or protect from disease, or influence each patient's individual response to medical treatment. This understanding is rapidly advancing, putting genomics at the heart of future precision, or personalised, medicine (Rehm, 2017).

Our understanding of the relationship between DNA variation and disease remains heavily biased to one subset of the human species, since most available human genome sequence data comes from individuals of European ancestry. DNA sequence variations that occur very infrequently, or are inconsequential, in people with European ancestry may play important roles in people with non-European ancestry, for example a variation in the *CREBRF* gene impacts body mass index (BMI) and type 2 diabetes risk in Māori and Pacific (Polynesian) people much more frequently than it does in people of solely European ancestry (Krishnan *et al.*, 2018). Alongside this inequity in the understanding of human genomes, MBIE's 2017 report on public engagement with science and technology revealed that engagement with science and technology among people with Pacific Islands ethnicity has fallen since 2014 and that Māori trust in the opinion of scientists and engineers has also declined (MBIE, 2017). Therefore, from the standpoint of health equity in New Zealand, research to better understand genomic variation in Māori and Pacific people is required. To generate engagement and truly benefit communities while avoiding harm, this research may need to be led and governed by Māori and Pacific people, with attention to kawa, tikanga and data sovereignty (Merriman & Cameron, 2007; Hudson *et al*., 2016; Beaton *et al*., 2017). The New Zealand Government's $35M investment in Genomics Aotearoa is one example of a genomics research platform that aims to address health equity issues in a culturally responsive way. Another approach to encourage Māori participation and expertise in genomics is the SING Aotearoa program (Bardill *et al*., 2016). New Zealand is not unique in programs that aim to address these types of inequity. For example, Desmond Tutu recognised the role of genomics in the future wellbeing of South African peoples, following very significant inequality and oppression. This inspired him to have his own genome sequenced as part of the Southern African Genome Project (Tutu, 2011).

The Auckland Genomics Into Medicine program seeks to generate a high output network of researchers, clinicians and patients/community focussed around evidence-based genomic medicine. For the reasons outlined above, to achieve this goal long-term the field of human genomics needs to engage current New Zealand students, including Māori and Pacific students.

2. OVERVIEW OF SCIENCE – EDUCATION PARTNERSHPS IN THE AUCKLAND REGION

Diverse but largely independent science educational partnerships operate in the Auckland region.

Many factors contribute to a piecemeal approach to educational partnerships between academic scientists and teachers in New Zealand: New Zealand scientists work in a competitive international environment, making do with relatively limited funding apportioned by short term performance-based mechanisms that do not incentivise science outreach efforts. Teachers are busy and many primary trained teachers or non-specialist science teachers may feel poorly equipped to bring science into the classroom, having limited professional development opportunities and access to peer support networks to stay abreast of rapid and sometimes disruptive advances in science and technology (Hipkins & Hodgen, 2012; Sexton, 2018). Moreover, even established and successful science partnerships with teachers may fall prey to the vagaries of funding and shifting institutional priorities. Despite these and many other barriers to partnership between academic researchers and teachers, there is a wide range of energetic outreach efforts underway in the Auckland area. To obtain a snapshot of some of these and identify what aspects of science partnership teachers find most valuable, Genomics Into Medicine held a symposium at the University of Auckland Medical School, on April 5th 2018.

Over 60 participants attended the symposium, with representation from teachers at many Auckland primary, intermediate and secondary schools. Also in attendance were members of the University of Auckland Faculty of Medicine and Health Sciences (FMHS), the School of Biological Sciences (SBS) and Centre for eResearch (CeR), representatives of the Auckland Museum, members of Rotary, researchers from the government Crown Research Institutes Plant & Food and the Institute of Environmental Science and Research (ESR), and individuals from entities having an explicit focus on science-based school partnerships and public outreach. Eighteen participants presented their experiences of delivering science content to school students and to the public, as discussed below.

Jacquie Bay summarised insights that drew on more than a decade of partnership with schools and the community in her capacity as Director of LENScience (the Liggins Education Network for Science) and, before that, her experience as Head of Science at Diocesan School for Girls. An important focus of the LENScience program (LENScience) is to increase scientific and health literacy of the public as it relates to noncommunicable diseases, such as obesity, and the concept of developmental origins of health and disease (DOHaD). A central theme of Jacquie's talk was that effective knowledge translation requires *sustained* multi-sectoral *partnership* between scientists, science educators, students and the public (Bay *et al*., 2016). A notable consequence of the LENScience Healthy Start to Life Education for Adolescents Project (HSLEAP) was that a high proportion of students communicated their learning about nutritional behaviour to their families (Bay *et al*., 2017a). Thus, schools can play an important role as a conduit for translating science knowledge into whānau and broader community understanding, a finding we will return to later.

Based on successful past projects, Jacquie emphasised two further elements as crucial for effective communication of scientific research:

1) Scientific literacy and learning is most efficient when contextualised in real-world issues that the students and their families can relate to. HSLEAP is based on a narrative pedagogy framework, providing students the opportunity to explore socioscientific issues through stories about the work of scientists, stories about individuals affected by noncommunicable disease (e.g. obesity) and stories from the student's own whānau or community that they bring with them, into the classroom environment (Grace & Bay, 2011).

2) Scientist-science educator partnerships need to be based on a pedagogically sound foundation and built-for-purpose, with attention to the learning priorities of schools and curricular guidelines of the national education system. This necessitates a close working relationship between scientists and teachers. At the same time, the pedagogical framework and associated learning resources must be sufficiently flexible to enable teachers to develop learning programmes that meet the differing needs of students within the school, address local circumstances at the time of delivery (such as the particular community the school resides in, current news items, or even the nature of a given class), and link directly to strategic goals of the school community (Bay *et al*., 2017b).

Shawn Cooper, who has worked with Jacquie Bay in the past, reinforced many of the above points. Shawn pointed out what he views as one of the great strengths and attractions of New Zealand's nonprescriptive curriculum, emphasizing that the 'Nature of Science' aspect of the curriculum gives students the opportunity to explore their culture and community to find solutions important to them. It is not so much the findings that students make in school science that are important, more the story and the journey they travel along the way. Shawn has played a major part in facilitating student journeys into science through his involvement in the New Zealand International Biology Olympiad Programme (nzibo.org).

Sarah Boasman, Head of Science and a biology teacher at Auckland's Diocesan School for Girls, provided a teacher's perspective on key features of school science and science education partnerships. In 2014, she was awarded an Endeavour Teacher Fellowship, administered by the Royal Society of New Zealand, which provided an opportunity to spend six months working on breast cancer in a research laboratory at the University of Auckland. This experience highlighted for her the potential impact of genomics on society and also what foundations and skills students need to develop at school in order to prepare themselves for tertiary study. Sarah's talk also highlighted the importance of fostering in students transferable abilities that are critical in science as well as other walks of life, such as relationship building, cross-curricular thinking, troubleshooting, and assessment of the veracity of information to which students are exposed. She pointed out that the New Zealand Curriculum has a strong focus on skill development and, like Cooper, extolled the value of 'Nature of Science' as a key focus in the curriculum. However, years 11-13 students need to prepare for exams and teachers need to adhere to prescribed key concepts, restricting the opportunity for a freer engagement with science at senior secondary school level.

Patsy Hindson, a science teacher from Saint Kentigern Boy's School provided a teacher's perspective on school science and science education partnerships when working with primary and intermediate school-aged students. Patsy talked about the value of learning through practical experiments and model making in the classroom. She demonstrated how students were motivated and enthused through the NIWA Auckland Science and Technology Fair, with which she has been involved as Treasurer and Lead Judge (scifair.org). The fair created an opportunity for boys from Saint Kentigern's to do research in an area that is relevant and interesting to them. Patsy's school has also held symposia where the boys' projects were displayed and scientists were invited into school to talk about their research. The symposia proved to be inspirational for students and parents alike and created an opportunity for the students to be put in touch with researchers for future potential collaboration.

Three speakers discussed programs of science partnership that were specifically directed toward students that might not be as well served as other groups within the Auckland region.

Brian McMath is Business Development Manager for NZ Product Accelerator and keenly interested in collaboration between industry and science. He is also Chairman of the Newmarket Rotary Charitable Foundation. Brian briefly discussed Rotary's Sci-Tech Experience program, which involved hands-on science activities for year 11 (NCEA level 1 students) at Auckland University of Technology (AUT) Manukau Institute of Technology (MIT) & Unitec NZ. The Sci-Tech program (sci-tech) is currently undergoing a hiatus and may emerge in a different form. However, Brian described Rotary's ongoing commitment to STEM education in schools through their donation of 3-D printers to 50 low-decile schools. **Henry Luo**, a graduate student at SBS described his work with OMGTech! (omgtech) an organisation founded by Zoe Timbrell and tech entrepreneur Vaughan Rowsell. OMGTech! focuses on putting technology in the hands of primary and intermediate school students, prioritising children from lower decile schools with limited access to expensive technology. **James Hucklesby**, a PhD student at SBS, is working with the New Zealand Association for Gifted Children (NZAGC) James explained how gifted students relish the opportunity to be extended beyond the regular teaching programme and, in so doing, avoid boredom and disengagement. Based on James's experience of working with gifted children, he advised against starting with basic groundwork; jumping straight to fun but challenging activities that were often done with parents participating alongside.

Angela Tsai and Debbie Young, both from FMHS, summarised the extensive range of science outreach programs they are involved in.

Angela Tsai is a Professional Teaching Fellow for the School of Medical Sciences, whose work involves connecting the community with local scientists and teachers. In addition to working with Shawn Cooper in NZIBO, Angela also contributes to FMHS's hosting of the Rotary National Science and Technology Forum (Rotary NSTF). This Rotary-sponsored two-week full residential programme is for outstanding Year 12 students who are intent on studying the sciences or technology at tertiary level. The forum provides these students with a fuller appreciation of the place of science and technology in the wider community. For the past several years, one activity during the forum has been the visit to the lab of Professor Cristin Print to learn about cancer genomics. Angela also talked about the Whakapiki Ake Project (Whakapiki Ake), part of the FMHS Vision 20:20 plan to increase the number of Māori and Pacific health professionals to 10% of the health workforce by the year 2020. Whakapiki Ake actively engages with rangatahi Māori enrolled in secondary schools to promote health as a career, working with students starting in Year 9. Angela also promoted the University's STEM online resource (STEMonline) as a terrific interactive platform for students and teachers, tailored to NCEA externally assessed standards.

Debbie Young, Associate Director of Outreach at the Centre for Brain Research (CBR), described three programmes the CBR is involved in. The first of these, 'Being Brainy', has been developed by neuroscientists at the Universities of Auckland and Otago, including Associate Professor Bronwen Connor, recently inducted as a Member of the New Zealand Order of Merit. 'Being Brainy' enables science and technology engagement by students at primary and intermediate school level using the example of the human brain. The programme provides free defined lesson plans to teachers and currently there are approximately 130 New Zealand teachers registered on the site (BeingBrainy). The CBR is also involved in The New Zealand Brain Bee Challenge (nzbbc), which is a competition for Year 11 high school students to learn about the functioning of the brain, the latest discoveries in neuroscience research and career opportunities in that field. Additionally, in conjunction with the Neurological Foundation, the CBR holds an annual Brain Day to coincide with an international Brain Awareness Week. Brain Day includes health workshops, discussion groups, interactive research labs and engaging science experiments for children and adults (BrainDay).

Museums play an important role in student and public engagement with science and technology (MBIE, 2017; Andre *et al*., 2017, Mujtaba *et al*., 2018). Claire Lanyon, Sarah Berry and John McIntyre outlined the scope of Auckland Museum's interaction with the public, which is targeting 1.2 million visitors annually by 2022.

Claire Lanyon is the Learning Manager at the Auckland Museum and she discussed the museum's partnership with teachers and Cognition Education to develop materials that will empower learners to understand and contribute to a changing world. The museum aims to work with 100,000 students, on site, over the next five years. As part of the Ministry of Education's 'All Equity Fund', the Museum is implementing a digital curriculum, in partnership with Te Papa, MTG Hawkes Bay and Waitangi Museum, to give high priority learners an opportunity to develop and share their own stories about their communities, the wider region and stories of national significance. Claire also expressed the museum's enthusiasm in partnering with Genomics Into Medicine program to deliver genomics-based learning opportunities at the museum.

Sarah Berry, Research Manager at the Museum emphasised the importance of close collaboration with Iwi and described the the Kapowairua BioBlitz - a partnership between Ngāti Kuri and Auckland Museum which aims to document the biodiversity within Ngāti Kuri's rohe and give this 'lost' knowledge back to the iwi, their kaumātua and tamariki (Kapowairua).

John McIntyre is president of the Auckland Museum Institute, which is also the Auckland branch of Royal Society Te Apārangi. John gave the museum's perspective on the importance of learning through engagement and knowledge sharing and also mentioned other initiatives to engage members of the public, including Café Scientifique and Café Humanities (Cafés), informal monthly meetings at the Horse and Trap (Mt Eden) that feature a short presentation by an expert (from a wide range of topics) followed by debate over a meal or drink.

Siouxsie Wiles and Damian Christie have been recipients of the Prime Minister's Science Communication Prize (in 2013 & 2017, respectively) and explored their experiences in communicating science to the public.

Siouxsie Wiles is an Associate Professor and head of the Bioluminescent Superbugs Lab at FMHS and is passionate about demystifying science for the general public and raising awareness of the growing threat of antibiotic-resistant superbugs. To illustrate the type of science content that captures the interest of members of the public, she showed an engaging, informative and entertaining video about using microbes found on feet to make cheese. Siouxsie is an active blogger (sciblogs), an online podcaster, a commentator on Radio New Zealand and appears on TV shows to discuss science stories in the news.

Damian Christie provided insightful perspectives on structural impediments to increasing public science literacy and engagement through mainstream media channels. He remarked on the fact that, in addition to the constant bombardment of material we receive through the media, audiences are also more fragmented than they have ever been before. A primary driver of this trend is that online sources now represent a major channel for the acquisition of news and information, and the content we consume is consequently self-curated. In the past, reading the newspaper would have exposed us to a wider range of viewpoints and newsworthy items we weren't expressly looking for. Algorithms directing our attention to material that fits with our prior informational search patterns exacerbate this problem. Furthermore, pop culture ephemera (e.g. celebrity, sport) exercises an outsized influence on the public's attention, to the detriment of engagement with science content. Damian's strategy to overcome these hurdles in science communication is to produce short, compelling, segments of science content for New Zealand's major media companies. Capitalising on these existing platforms, Damian's company, Aotearoa Science Agency (scienceagency), has produced video stories that over a short period received 1.5 million views. Damian is always on the lookout for interesting stories and people to work with.

Only one talk at the symposium focused on science partnerships with New Zealand school students in the context of genomics. **Justin O'Sullivan**, Associate Director for Research at the Liggins Institute, described the serendipitous origin of a 2011 Katoa project, a citizen science-based metagenomic study of the microbial population at hot water beach, Coromandel which involved 60 students from 4 schools over a weekend (katoa). Through this project, high school students and teachers were able to delve into the practical and theoretical aspects of a real-life scientific investigation of soil microbiology. Justin pointed out that a major issue in scientist-science educator partnerships is that they are usually cobbled together on a shoe-string budget, and current academic funding models (i.e. based on publications) do not recognise the substantial effort that goes into developing and sustaining such efforts, or the long-term value of such investment activities. The Katoa metagenomics program is now being run, in modified form, by Dr. Nikki Freed, Massey University, Albany (metagenomics).

The remaining two speakers at the symposium provided international insights, from the United Kingdom, on genomics public outreach.

Polona Le Quesne Stabej talked about genomics workshops at open day events at Great Ormond Street Institute of Child Health (GOSICH) in London. Open days at GOSICH are annual events for the general public aimed to raise awareness of child health research through seminars for adults (100,000 Genomes project talks by Genomics England) and hands on workshops for children. Genomics workshops modelled the process of DNA sequencing and demonstrated how DNA variants can be the cause of genetic diseases using lego® bricks. Polona has recently joined the University of Auckland to work on translational genomics projects. She is also keen to help set up genomics educational events for schools and the general public.

Nicola Arrol recently moved back to Auckland having worked on the UK 100,000 Genomes project. Nicola presented the excellent work of Health Education England and Genomics England in educating and informing the general public of the benefits of genomic medicine through many informative tutorials (Genomics England) Nicola emphasised that children from primary schools onward need to be taught about genetics and genomics and pointed out the need for governments to invest in genomic medicine (as exemplified by the UK's 100,000, France's 235,000 and the US one million genomes projects).

Despite the diversity of science partnership programs mentioned above, this is doubtless just a small slice of the efforts scientists and science teachers are putting into building student and public STEM engagement and scientific literacy in the Auckland region (including House of Science who were also represented at the symposium). Nevertheless, this sampling indicates that at present relatively little is being done in terms of *genomics-focused* scientist- educator partnerships in Auckland. This is generally true nationally, although one program deserving of mention is the Africa to Aotearoa project (A2A) run by molecular anthropologist Professor Lisa Matisoo-Smith (University of Otago Allan Wilson Centre). This involves a partnership with the Biology Educators' Association of NZ (BEANZ) with 250 science/social science teachers sending their DNA for analysis by the National Geographic Genographic Laboratory in the United States. An extensive teaching resource, linked to the NZ curriculum, has been developed in conjunction with this project (Who is a New Zealander?).

3. DIRECTIONS AND FUTURE PLANS FOR AN AUCKLAND GENOMICS INTO SCHOOLS INITIATIVE

Rationale for Genomics Into Medicine's plan to contribute to genomics education in Auckland schools.

Educational partnership with teachers and schools has been one part, albeit a relatively small part, of the Auckland Genomics Into Medicine program from the start. However, the considerations outlined above suggest this is a highly important aspect of our program and is something we cannot fail at, if we are to achieve the long-term goal of generating a sustainable, high output network of researchers, clinicians and patients/community focussed around evidence-based genomic medicine. Based on the partnerships summarised above, several points for consideration when generating new genomics partnerships emerge.

What age of students should we target? As pointed out by Sarah Boasman in her talk, and in discussions with **Rachel Heeney** (Head of Biology at Epsom Girls Grammar School), teaching of senior secondary school students is tightly geared to achieving NCEA success, potentially constraining the pedagogical approaches and content the Genomics Into Medicine Programme might hope to develop for classrooms, as well as the willingness of teachers to try something new in a high-stakes learning environment. Consequently, Genomics Into Medicine is focusing its efforts on students from years 7-10 (ages 10-14). This age bracket was similarly the target audience for Jacquie Bay and colleagues in the LENScience HSLEAP program. At a purely pragmatic level, this opens the possibility of developing units of work on genomics, with associated teaching resources, that would run across two to three weeks of school; something impossible in the packed curriculum at senior secondary school level. In HSLEAP, for example, each school developed a 4–6 weeks learning module (12–18 classroom hours) based around the framework that had been developed, but which they tuned to their own setting. In addition, during the module, students participated in a 1-day hands-on learning program at the Liggins Institute. We believe this general structure would also work well for new Auckland genomics educational partnerships, covering aspects of DNA, genetics and genomics in the classroom and, during or at the end of the module, a visit to the Auckland Museum for hands-on experience of genome sequencing.

Importantly, the HSLEAP program resulted in sustained changes in adolescent behaviour and transmission of learned information from students back to their families (Bay *et al*., 2012). This is exactly what we need to accomplish if our intent is to increase student interest in STEM careers (particularly in biology, medicine, bioinformatics and related fields) and simultaneously raise the public's genomic literacy. This overarching goal also motivates our plan to initiate new genomics education partnerships with intermediate school age children. An extensive series of studies conducted in the United Kingdom by Louise Archer and colleagues (Archer *et al*., 2013), surveying nearly 20,000 students, reveals that interventions to increase the number of students that aspire to STEM careers needs to begin at primary school age (ASPIRES). This is supported by similar findings in the United States (Tai *et al*., 2006). In the ASPIRES study, through ages 10-13, over 70% of students believe that they learn interesting things in science, that their parents think it is important they learn science, and that scientists do valuable work. However, irrespective of age, only ~15% of students want to *be* scientists **(Fig. 2)**. Family 'science capital' seems a key determinant of whether students aspire to a science-related career by age 14. In the HSLEAP study, student learning was transmitted to whānau, building up family science capital. Our new initiatives should be designed with the same end in mind.

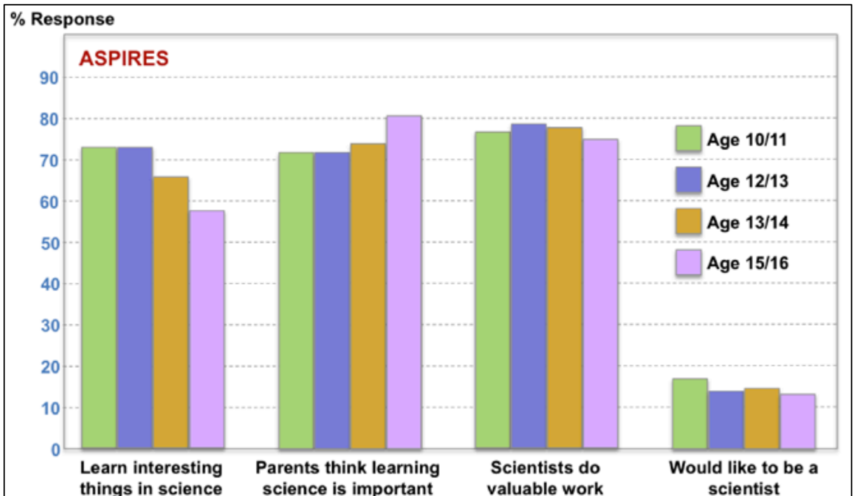

Figure 2. Enthusiasm for Science Does Not Beget Scientific Aspirations.

Views of school science and scientists are positive and not the root cause of the low percentage of students interested in careers in science. Figure 2 is adapted from Archer *et al.*, 2013 and a Louise Archer TEDx talk (accessible on youtube).

Introducing students to DNA, genetics and genomics at an earlier age than is typically the case in New Zealand schools might also have a more general advantage to their understanding of biology. Reprising Dobzhansky's famous remark that "nothing in biology makes sense except in the light of evolution" (Dobzhansky, 1973), Kalinowski and colleagues have argued that "nothing in evolution makes sense except in the light of DNA" (Kalinowski *et al*., 2010). As students advance through biology, they often carry with them misconceptions about natural selection and evolution that could be dispelled by expressing those themes in the context of DNA. Ideally, DNA, genetics and genomics would be introduced early in primary school; a useful model being CBR's Being Brainy program which provides teaching resources about the human brain for Year 1&2, Year 3&4, Year 5&6

and Year 7&8 students. This seems a productive approach to learning about biology, extending children's understanding of DNA's foundational role in the living world by incrementally advancing, through interactions with their peers and teachers, the Vygostskian zone of proximal development (ZPD), as it applies to understanding molecules, DNA, genetics and genomics (Vygotsky, 1978; Roosevelt, 2008). Thus, an earlier introduction to DNA might alleviate conceptual bottlenecks that discourage students from continuing in Biology, some of whom might otherwise have gone on to tertiary studies in genomics, bioinformatics or related subject areas.

What strategy should we adopt to foster genomics learning? A recurrent theme from speakers at the symposium was that science partnerships should maximise adolescent students' sense of agency in their learning, allowing them to build their sense of self-efficacy and regulate how and what they learn through student-centered instruction (Bandura, 2005; Granger *et al.*, 2012). Students are more likely to learn from their participation in classroom science if they have designed their own experiments, and/or if the experiment has personal relevance to them. Similarly, a self-referential learning bias is observed in medical students who are more engaged, and learn genetic and genomic concepts more quickly, when given the opportunity to analyze their own genome sequence data (Salari *et al*., 2013; Parker & Grubs, 2014; Linderman *et al*., 2018). Out of ethical and legal liability concerns, personal genome sequencing of high school students is typically avoided, although one notable exception has been the use of next generation sequencing of regions of the mitochondrial genome to examine the genetics of race (Yang *et al*., 2017). However, in New Zealand for the foreseeable future, sequencing of any regions of student DNA is perhaps a bridge too far.

Form & Lewitter (2011) have enumerated 10 rules for engaging high school students in bioinformatics (the branch of science involved in analysing genomic data), the second of which is to choose examples familiar and relevant to students. They note: "*High school students are particularly interested in topics that they can relate to their immediate personal or social lives. Choose genes, proteins, or processes that relate to disease, development, or other aspects of human physiology and behavior*. *Obesity, diabetes, and developmental disorders are some examples that have worked well*". However, in Genomics Into Medicine's conversations with New Zealand teachers, the concern was raised independently by several teachers that discussing genomic contributions to some human diseases or traits in a 'deficit model' carries the risk of upsetting students and their whānau if the diseases or traits hit too close to home, potentially reducing engagement and doing harm. Although public health issues such as obesity were a major focus of the LENScience HSLEAP project, perhaps such topics may be more confronting when genetics is brought into the picture. This remains an issue for further discussion.

Another framework for introducing genomics in the classroom is through fictional forensic scenarios. Students would use genomic sequence data to identify the perpetrator of a crime, from a group of suspects, based on physical and other traits. Fictional scenarios can recapitulate some of the ethical, moral and societal dimensions of genomics use in forensics, setting up crime scene scenarios in such a way that stereotypes and biases shaping assumptions about suspects can be invalidated by the genomics data. However, such scenarios need to be carefully crafted to avoid misinterpretation of ethnic or cultural diversity. A solid pedagogical rationale for this approach was provided at the symposium: Jacquie Bay's synopsis of the LENScience program noted that transformative learning occurs when students are led to examine their assumptions in such a way that habits of mind and social and cultural norms are challenged (Mezirow, 2003; 2011).

The issues discussed above create something of a conundrum: How do we develop genomics scenarios for the classroom that will have the widespread acceptance of teachers, student and whānau and that: 1) are familiar and relevant to students, 2) provide students with a sense of agency, 3) raise important social and ethical issues that surround genomics, and 4) have a connection to health and medicine (to fit with Genomics Into Medicine's aims)? It is perhaps unrealistic to expect that each of these criteria can be met by a single approach, and one-size-fits-all strategies tend to perform poorly in educational settings. As a starting point, Genomics Into Medicine intends to develop genomics educational materials that at least attempt to address the above issues, but which are sufficiently flexible to enable teachers to modify genomics scenarios to fit local circumstances. Consultation with National Science Facilitators and other science education specialists would be sought to guide further development of genomics resources in order to broaden their acceptance, appeal, uptake and utility.

For Year 7&8 students, initial genomics and bioinformatic teaching resources could be developed based around Lego® DNA analogy models (Rothhaar *et al*., 2006) and simple DNA sequence alignment tasks (Cooper *et al*., 2017), with discussion about the genetic basis of relatively innocuous human traits such as eye colour. During the module, a visit to the classroom by scientists, or a visit of a class to the technology centre of the Museum, would give students a close-up look at DNA sequencing happening in real time, using Oxford Nanopore Technology minion sequencing devices, which have recently been used in STEM activities in a New York middle school classroom (see PlayDNA and VCS) and that are already used in our research group.

For Year 9&10 students, utilisation of an already well developed narrative framework, such as the Planet of the Apes reboot movie series, or Avatar (of which multiple sequels are currently in development), would provide instant familiarity for many students/teachers/whānau and a more immersive experience. Students would be able to place themselves into character roles and explore ethical/social/moral issues around genomics that would be more difficult to broach in the real world context (analogously, see Madsen, 2013). Exploration of genomics in fictional settings has also been shown to develop students' opinion-forming skills (Knippels *et al*., 2009). Ultimately, for this age group, character-driven online interactive fiction based approaches could be developed that are compelling and thematically rich. An excellent example of this in the context of genomics and complex disease risk is provided by HudsonAlpha Institute's online game "Touching Triton" (Loftin *et al*., 2016; triton). Detailed aspects of the content and delivery of these scenarios and the learning modules they are embedded in are still being established, but particular pedagogical design features that facilitate learning (Hattie ranking) will be incorporated where possible. Following imaginary scenarios that enable student understanding of the basics of genetics/genomics, real-life examples from celebrities who have publically discussed their experience with genomic medicine could be presented; an area fitting well with the Genomics Into Medicine program's remit. Angelina Jolie's *BRCA1* status is widely known and often raised in classrooms. A local and culturally pertinent celebrity example is Māori singer Stan Walker's stomach cancer due to familial *CDH1* mutation (Stan Walker).

4. CONCLUDING REMARKS

Rapid progress in genomics has been likened to an unstoppable train (Maher, 2011) and, as Bandura has noted (2006), "*We are an agentic species that can alter evolutionary heritages and shape the future. What is technologically possible is likely to be attempted by someone. We face the prospect of increasing effort directed toward social construction of our biological nature through genetic design*." Even leaving aside the enormously fraught moral issues of designer babies, eugenics and the misleading and harmful misuse of genomic data (as has occurred for Māori; Lea & Chambers, 2007; Merriman & Cameron, 2007, Hook 2009), genomics raises many complex ethical issues. These issues lead to genomics-related decisions that current students will need to grapple with during their lifetimes. Therefore, it is essential that we equip students with the human genomic knowledge necessary to participate in informed debate. From its outset, The Auckland Genomics Into Medicine Program included educational partnerships in genomics between scientists and schools. However, the considerations summarised in this White Paper suggest that assisting where it can in human genomics education at school level is essential to achieve a long-term sustainable network of researchers, clinicians and communities/patients focussed around evidence-based genomic medicine. In particular, from Jacquie Bay's experience we learn that school and community education strategies need to be based on partnerships between scientists and teachers, rather than being based on scientist 'outreach' towards teachers. Ideally, these partnerships should generate teacher genomic experts who then drive ongoing development of genomics education for their students, as independent as possible of individual scientists but using their expertise and resources where useful.

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