

SCIENCE, TECHNOLOGY AND MATHEMATICS EDUCATION

in the Development of the Innovation and
Technology Ecosystem of Hong Kong



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Table of contents

Abbreviations	2
Introduction	3-4
About the authors	5-6
Executive summary	7-10
Background and current issues	11-14
Chapter 1: STEM and society	15-32
Chapter 2: Mathematics	33-50
Chapter 3: Cross-disciplinary skills and knowledge	51-64
Chapter 4: Language at the expense of STEM?	65-68
Chapter 5: Others: Information and Communication Technology (ICT)	69-72
Bibliography	73-76
Acknowledgements	77-80
The Academy of Sciences of Hong Kong - a brief introduction	81

Abbreviations

3-3-2-2	HKDSE Level 3 for Chinese, Level 3 for English, Level 2 for Liberal Studies and Level 2 for Mathematics
4C + 2X	Four core DSE subjects (Chinese, English, Liberal Studies, Mathematics) and two Elective subjects
AP Programme	Advanced Placement Programme
ASHK	The Academy of Sciences of Hong Kong
BAFS	Business, Accounting and Financial Studies
EDB	Education Bureau, the Government of Hong Kong Special Administrative Region
GCSE	General Certificate of Secondary Education
GDP	Gross domestic product
HKALE	Hong Kong Advanced Level Examination
HKCEE	Hong Kong Certificate of Education Examination
HKDSE	HKDSE Hong Kong Diploma of Secondary Education
HKEAA	HKEAA Hong Kong Examinations and Assessment Authority
HKU	The University of Hong Kong
HL	High Level, International Baccalaureate Diploma Programme
IBDP	International Baccalaureate Diploma Programme
ICT	Information, Communications and Technology
IELTS	International English Language Testing System
IT	Information technology
IVE	Hong Kong Institute of Vocational Education
M1	HKDSE Mathematics extended part Module 1
M2	HKDSE Mathematics extended part Module 2
OECD	The Organisation for Economic Co-operation and Development
PISA	Programme for International Student Assessment
R&D	Research and Development
SL	Standard Level, International Baccalaureate Diploma Programme
STEM	Science, Technology, Engineering, Mathematics
TIMSS	Trends in International Mathematics and Science Study
TMT	Technology, media and telecommunications
UGC	The University Grants Committee
US	The United States
VTC	Vocational Training Council

Introduction

“We cannot solve our problems with the same thinking we used when we created them.”

Albert Einstein

As innovation and technology take centre stage in countries’ development strategies, STEM¹ education has emerged in national agendas in recent years. It is the cornerstone behind many of the scientific and technological innovations that have benefited mankind; be they healthcare, energy sources, new materials, protection of the environment, Internet or other new industries. Engaging students in STEM disciplines, fostering critical thinking to approach scientific and non-scientific matters and cultivating STEM literacy are therefore essential to ensure adequate supply of talent as well as to fulfil our role as global citizens.

Hong Kong needs to invest in innovation and technology in order to diversify and develop into a knowledge-based economy. Hence, STEM education has also become an important agenda. However, although our children and youths in Hong Kong have performed well in international science and mathematics tests, there is a disconnect between those high test scores and student engagement in STEM at senior secondary and post-secondary study as well as in their career choices. While STEM is required for some attractive jobs available in areas such as finance and medicine, our weak manufacturing base and low investments in R&D have stymied efforts to build a strong STEM talent pool. This in turn hampers our ability to move up the value add, hence creating a vicious cycle that hinders innovation.

The territory’s education reform of the last decade has greatly responded to society’s changing needs brought about by new technological advances as well as by globalisation. Educational opportunities, both at senior secondary as well as post-secondary, have been broadened. Mathematics, the foundation of scientific and logical thinking, has been made compulsory to all senior secondary students. Indeed, a continuous effort to improve the system is needed to take into account all aspects of STEM in our education programmes; to cultivate interests in STEM by highlighting its relevancy to daily life, to foster attitude and skills of systematic investigation and ideas formulation as well as to implant a solid foundation of scientific knowledge for further advanced studies or career development. The Education Bureau of the Hong Kong SAR Government has recently published a report on STEM education as part of the ongoing renewal of School Curriculum².

This paper is drafted under the auspices of The Academy of Sciences of Hong Kong. It attempts to look at one facet of the ecosystem underlying the development of STEM education in Hong Kong; namely STEM at senior secondary education. It is an extension of the report from Our Hong Kong Foundation: *The Ecosystem of Innovation and Technology of Hong Kong*³ which looks at factors behind the

¹ STEM is an acronym that refers to the academic disciplines of Science, Technology, Engineering and Mathematics collectively. In the curriculum context of Hong Kong, STEM education is promoted through Science, Technology

² Report on Promotion of STEM Education – Unleashing Potential in Innovation, Education Bureau, December 2016 (http://www.edb.gov.hk/attachment/en/curriculum-development/renewal/STEM%20Education%20Report_Eng.pdf)

³ <http://ourhkfoundation.org.hk/index.php/2015-09-23-05-07-31/2015-12-16-09-14-10>

building of innovative capacity needed to diversify Hong Kong into a knowledge-based economy. **This is by no means a comprehensive report.** Issues such as STEM workforce and the labour market, vocational training and Applied Learning studies (i.e., Category B in HKDSE) under the new senior secondary education have not been included in our discussion but can be subjects in future studies. Nor does our report cover the entire education spectrum such as primary, junior secondary or adult education which are all important stages of one's life-long education. As such, this report, although intended for all stakeholders, merely serves as a starting point for in-depth discussion among all and for further amendment by all.

As part of the study, the authors conducted extensive consultations and roundtable discussions between May and November, 2016. A survey of secondary school principals (Questionnaire on Senior Secondary School STEM Education) was conducted under the name of the Academy in October of the same year. The authors are particularly grateful to the support rendered by Hong Kong Subsidized Secondary Schools Council, Hong Kong Association of the Heads of Secondary Schools, Hong Kong Direct Subsidy Scheme Schools Council, the Association of Principals of Government Secondary Schools, the Association of Mathematics and Science, the Education Bureau, the Hong Kong Examinations and Assessment Authority, and the eight UGC-funded universities: The University of Hong Kong, The Chinese University of Hong Kong, The Hong Kong University of Science and Technology, The Hong Kong Polytechnic University, City University of Hong Kong, Hong Kong Baptist University, Lingnan University and The Education University of Hong Kong. Special appreciation must also be expressed to Dr Catherine K K Chan, Mr Antony Leung, Professor Cheng Kai-Ming, Professor Kenneth Young, Mr Tai Hay-Lap, Professor Cheung Yan-Leung, Stephen, Dr Tong Chong-Sze, Mr Lam Yat-Fung, James, Mr Lau Kwok-Leung, Gyver, Ms Lee Suet-Ying, Dr Chiu Cheung-Ki, Dr Cheng Kin-Tak, Samuel, Dr Poon Suk-han, Halina, Mrs Lau Kun Lai-Kuen, Stella, Mr Wong Kwong-Wing, Dr Chan Wong Lai Kuen, Anissa, Mr Tang Chun-Keung, Teddy and Mrs Fung Lai Miu-Yee, Bonnie, who have provided valuable insights and critical comments for our report.

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Executive summary

As innovation and technology are being increasingly recognised as the locomotive to drive sustainable development and solve complex global challenges, STEM⁴ education has emerged in the top national agenda of many governments in recent years.

Compared to other countries and regions, Hong Kong has top achievement and positive student attitudes towards STEM, as measured by global assessment tests of PISA⁵ and TIMSS⁶ of students at or below age 15. Such attainments, however, are not being translated into high enrolment in STEM-related subjects at the senior secondary education level. This disconnect is manifested in three main ways:

1. STEM education not being extended to all students. Despite the abolition of tracking and the transition into a broad-based education system, almost half of the new senior secondary students in Hong Kong do not take any Science or Technology subject, whereas in the US, Europe and many Asian countries, Science is compulsory and cross-Arts-Science study is part and parcel of many broad-based education systems.

2. Poor enrolment in advanced Mathematics studies. Student enrolment in advanced Mathematics dropped from 23% in 2012 to 14% in 2016, relative to 25% of students taking Additional Mathematics⁷ before the implementation of the current Diploma for Secondary Education in Hong Kong (HKDSE). It is alarming that Hong Kong students' participation rate in advanced Mathematics is much lower than that in Singapore and New Zealand (40%) and far behind those in Japan, Korea and Taiwan (57-80%).

3. Broad-based scientific training on decline. Innovation and scientific research, as well as the ability to solve complex problems nowadays require multidisciplinary training and possession of so-called "T-shaped" knowledge. However, over two-thirds of HKDSE students took only two Electives, comparing poorly to an average of four subjects in addition to Languages and Mathematics previously (under the HKCEE⁸ system). The narrowed knowledge base seriously weakens the foundation required for articulation into post-secondary education.

The lack of a strong manufacturing base and the weak R&D spending by government and corporate bodies are generally believed to have dampened students' enthusiasm towards STEM in Hong Kong. Consequently, many high-performing

⁴ STEM is an acronym that refers to the academic disciplines of Science, Technology, Engineering and Mathematics collectively. In the curriculum context of Hong Kong, STEM education is promoted through Science, Technology and Mathematics Education (Curriculum Development Council of the Education Bureau of the Hong Kong SAR government, November 2015)

⁵ The Programme for International Student Assessment (PISA) is a triennial international survey by the Organization for Economic Co-operation and Development (OECD). It aims to evaluate education systems worldwide by testing the skills and knowledge of 15-year-old students.

⁶ Trends in International Mathematics and Science Study (TIMSS) is a series of international assessments by the International Association for the Evaluation of Educational Achievement of the Mathematics and Science knowledge of students around the world.

⁷ Under the Hong Kong Certificate of Education Examination (HKCEE), which was a standard school-leaving examination for students who finished five years of secondary school between 1974 and 2011.

⁸ HKCEE Hong Kong Certificate of Education Examination (1974-2011).

students opt to study medicine, business or law at universities, while Faculties of Science and Engineering have relatively more difficulty in attracting students with high academic achievements. This self-perpetuating cycle further weakens the region's STEM-readiness to "re-industrialise".

University admission policies also play a pivotal role in shaping student behaviour. Currently, strong emphasis is being placed on the examination results of the four Core Subjects⁹. Thus, the examination-oriented culture among students in Hong Kong compounds with the limited supply of government-funded university places, poor prospects in studying science and engineering, and unfavourable social attitude towards diploma programmes and vocational education as alternative pathways are all contributing factors, leading to narrowing of studies and general risk-aversion among students and, ultimately, impeding their holistic development. A survey conducted by ASHK on senior secondary school principals finds that STEM enrolment is stymied by two critical factors, including:

1. **Over-emphasis on Core Subjects.** While the Core Subjects in HKDSE were originally designed to provide students with balanced knowledge required for their competencies in their further development, over 55% of the 154 respondents in our survey of secondary school principals (representing 31% of all secondary schools in Hong Kong) reported that they spend over 60% of their normal teaching hours on the four Core Subjects, in which STEM content is relatively low. Moreover, among the 89% of respondents offering after-school-hour classes, 69% named the Core Subjects among the top-three subjects taught after school. This peculiar behaviour is clearly being driven by the local university admission policies.
2. **Poor recognition of advanced Mathematics.** Under the HKDSE, advanced Mathematics under two extended modules, namely M1 and M2, are not offered as full subjects but as "half-courses" to "extend" students' Mathematics education beyond what is offered in Mathematics under the Core Subjects. Given the tight teaching schedule on Core Subjects, the two extended modules M1 and M2 are often relegated to after-school-hour classes. In addition, not all universities recognise M1/M2 as full Electives or make specific demands on them as admission requirements. These could hardly be incentives for students with high mental and logical capacities to opt for advanced Mathematics given the strenuous efforts required.

⁹ The four Core Subjects under HKDSE are Chinese Language, English Language, Mathematics and Liberal Studies

Recommendations:

Hong Kong needs to build up its innovative capacity and to raise the overall STEM literacy in order to diversify into a knowledge-based economy. As information and technological changes gather pace, the amount of knowledge to be acquired by our next generation is becoming increasingly formidable. While education systems need to respond to the above changes, our assessments and university admission systems also need to adapt and evolve to suit the needs of the new world. As STEM education is an integral component of the ecosystem of innovation and technology, as well as the overall literacy of our knowledge economy, all stakeholders including businesses, governments, non-governmental agencies, students and parents must develop an open mind to embrace new perspectives when designing what is best for our future generations.

To enhance the STEM literacy and raise the science and technology expertise in Hong Kong, we recommend the following:

1. Trim the Core Subject requirement to achieve a balance between Science and Non-Science education. Understanding the physical world and how Science works is essential for one to work and live in the 21st Century, STEM education should constitute an important part of a child's education. The Core Subjects of the HKDSE curriculum, as designed, offer limited STEM content. To encourage students to broaden their knowledge horizon and to strike a balance between Science and Non-Science subjects in our senior secondary education, the emphasis on Core Subjects needs to be trimmed to make room for more Elective subjects, especially for Science-related subjects.

2. Introduce module flexibility to provide choice for students in choosing Science subjects. Students have wide differences in interests and aptitude in their orientation towards Science subjects. A broad-based education system needs to provide adequate flexibility to cater for students' learning diversity. Offering Basic and Advanced level syllabuses will enable students to develop breadth and depth, or the so-called T-shaped knowledge that is needed for the 21st Century, while encouraging students to take cross-Arts-Science studies. We recommend an introduction of module flexibility by phase, starting with the Core Subjects, and gradually extend it to the major Elective subjects over time. Module flexibility is best supplemented with flexibility in the assessment system.

3. Give proper recognition to advanced Mathematics to stimulate enrolment. Improved mathematical skills is essential in an increasingly technology-and-data-centric world beyond the traditional boundary of science and engineering. To extend the appeal of advanced Mathematics to a wider group of students and to encourage school provision, it is important to give proper recognition to the subject, which is currently treated as half subjects or extended modules. We recommend putting Mathematics Module 1 and Module 2 back into the Core Subjects, by creating three "alternative" Mathematics Core offerings to cater for students with different study or career pathways. An alternative option would be to place advanced Mathematics as a separate Elective. In either scheme, universities must give clear signals in their admission policies to guide students in their requirement in Mathematics.

4. Universities to review the “3-3-2-2” common minimum entrance requirement and individual programme admission requirements to encourage students to take more Science subjects. University admission policy has a strong impact on senior secondary schools’ curriculum. The current 3-3-2-2 minimum requirement (for the four Core Subjects: Chinese-English-Math-Liberal Studies) for the eight UGC-funded universities and the well-intended “5-best subjects” scoring method for some programmes, have resulted in a disproportionately large amount of time spent on the four Core Subjects, leaving inadequate time for Elective subjects. Universities should be given institutional autonomy in stipulating their minimum entrance requirement. We recommend that universities review their admission policies to enable students to build a strong foundation of scientific knowledge across disciplines. Most important, admission criteria should be aligned to the needs of the individual programmes.

5. Diploma of Secondary School Education. Although there is no ‘passing’ threshold for the HKDSE as originally designed, the introduction of 3-3-2-2 as the minimal requirement for admission to the eight UGC-subvented universities has unintentionally created a new measurement of success, which is unattainable for most school leavers. Therefore, we strongly recommend that proper recognition should be given to students who have attained adequate senior secondary education. The minimal requirement for secondary school graduation should be set with a standard to ensure students attain the necessary core skills and knowledge deemed essential to prepare them for further study or career development. In other words, secondary school certification should be decoupled from tertiary admission standards.

Background and current issues

The promotion of STEM education aims to develop students to become lifelong learners of science, technology and mathematics, enabling them to meet the challenges in the 21st century, and from a wider perspective, nurturing versatile talents with different levels of knowledge and skills for enhancing the international competitiveness of Hong Kong, and in so doing contributes to national developments.

The major objectives to achieve in STEM education include developing a solid knowledge base among students and enhancing their interest in Science, Technology and Mathematics; strengthening their ability to integrate and apply knowledge and skills; nurturing their creativity, collaboration and problem solving skills; and developing talents/experts in STEM-related areas to foster the development of Hong Kong.

*– Report on **Promotion of STEM Education***

– Unleashing Potential in Innovation, Education Bureau December 2016

In December 2015, Our Hong Kong Foundation published a research report entitled *The Ecosystem of Innovation and Technology of Hong Kong*. It looks into the value chain of technology innovation and entrepreneurship and explores the opportunities and challenges facing the tertiary education, the business sector and the government of Hong Kong in this area. In particular, it highlights Hong Kong's low business and public R&D funding, as a percentage to GDP and a disconnect between upstream, academic basic research, and their socio-economic impact. In response, the government has launched several initiatives including the establishment of a HK\$2 billion fund to support midstream, translational research as well as a similar amount of matching-type investment funds to help start-ups in Hong Kong.

STEM education has been identified as a weak link in the development of innovation and technology in Hong Kong. Concerns include whether the new (senior) secondary education system has adequately prepared our students for the breadth and depth of scientific knowledge and skills of critical thinking that are needed for creative innovation. Other concerns such as the lack of universal computer coding training, a skill deemed essential to hone students' logical thinking and is widely sought after nowadays in the Internet-centric economy, are also raised. In December 2016, the Education Bureau released its report on *Promotion of STEM Education – Unleashing Potential in Innovation* that recommends updating the curricula of Science, Technology and Mathematics for P1-S6 and promoting student-centred, in-school as well as out-of-class STEM learning activities.

The present study attempts to look at the status of Science, Technology and Mathematics education in Hong Kong at the pre-tertiary, especially senior secondary, level with an aim to identify ways to enhance it. It adopts a mixed qualitative and quantitative approach. Through extensive interviews and focus groups discussions as well as analysis of statistics, we first identify key issues and generate some hypothesis. A survey is then conducted among secondary school principals to verify

the qualitative findings, to seek explanations of data statistics and to collate views on proposed remedies.

As part of our initial consultation with school principals and other stakeholders in May 2016, a number of issues relating to the development of STEM education in Hong Kong sprang up. They include:

- **STEM literacy.** One of the touted goals of the educational reform introduced by the HKDSE under the Education Bureau (EDB) of Hong Kong is to promote a holistic education among students. With the abolition of school tracking (i.e., dividing students into Arts and Science streams), there has been the hope that the new system would encourage students to take both Humanities as well as Science subjects. Unfortunately, the good intention has apparently been negated by the examination and assessment system accompanying the HKDSE reform. Consequently, almost half of the HKDSE students have not elected a single Science or Technology subject in their choice of Electives, resulting in a situation that is only slightly better than the old tracking system. In other countries in North America and Europe, Science is compulsory and cross-Arts-Science-study is part and parcel of many broad-based education systems.
- **Study of advanced Mathematics.** The biggest disappointment has been the decline in the number of students studying Mathematics Module 1 (Calculus and Statistics) and Module 2 (Algebra and Calculus), which are two ‘half-courses’ defined by HKDSE to ‘extend’ students’ mathematics education beyond the Mathematics subject among the Core Subjects. The proportion of school leavers who have taken M1 or M2 dropped precipitously from the initial 23% of the cohort in 2012 to below 14% in 2016. As a comparison, around 25% of students in the old school system (Hong Kong Certificate of Education Examination¹⁰) took Additional Mathematics in 2010. In Singapore and New Zealand, advanced mathematics’ take up rate is 40% of the upper secondary age cohort (J. Hodgen, 2013).
- **Multi-disciplinary scientific training.** Innovations and modern scientific research require inter-disciplinary interactions and collaborations, which in turn necessitate a solid training of physics, chemistry, or biology and in some instances, computer science as foundation. Currently, around two-thirds of HKDSE candidates take four Core Subjects (Chinese Language, English Language, Mathematics and Liberal Studies) plus two Electives. The latter embeds the freedom to choose between Humanities and Science subjects. While the intention has been to promote STEM literacy of the entire population, there are concerns about a lack of adequate training for those who wish to pursue further study and training in science and engineering programmes. As a comparison, under the previous HKCEE system, students who were in the Science track have two years (Forms 4 and 5) of broad science training before specialising on their science electives, while under the current system, students who plan to pursue further studies in science may not have any training on physics, chemistry or biology after Secondary 3.

¹⁰ HKCEE: Hong Kong Certificate of Education Examination was a standard school-leaving examination for students who finished five years of secondary school between 1974 and 2011.

- ***The impact of language focus on STEM education.*** One of the goals of the senior secondary education reform is to enhance language proficiency of students to enable self-directed learning. Three of the four Core Subjects are either language (Chinese and English) or language-focused (Liberal Studies). Moreover, Chinese Language and English Language have a minimum requirement of Level 3 for university admission, whereas Mathematics and Liberal Studies, Level 2. For those science students who are gifted in Science and Mathematics but less proficient in language abilities, the current system forces them to take extra effort to master languages and may have even excluded a small fraction of them in getting university education.

Our survey of secondary school principals on their views regarding STEM education was conducted between 1 and 15 October 2016. Questionnaires were sent out to 504 secondary school principals and 154 replies were received with a response rate of 31%. It is perhaps important to highlight that, as part of our recommendations, international practices are drawn for reference but adapted to suit Hong Kong's unique situation.

Chapter 1: STEM and society

“Science is not only a discipline of reason, but, also, one of romance and passion.”

Stephen Hawking

***Summary.** Despite the abolition of tracking and the transition into a broad-based education system, almost half of the new senior secondary students do not take any science or technology subject. Our survey finds that school principals believe the major reason is that arts-oriented students find the science curricula too difficult and that may have a negative impact on their HKDSE score. This echoes research which raises concerns that high stakes examination narrows the curriculum and students’ learning. In many broad-based education systems globally, science as well as well cross-arts-science study, are made compulsory to broaden student’s knowledge horizon. More importantly, module flexibility and student-centred freedom to choose electives are offered to enable students to take contrasting subjects. In Hong Kong, both of these are provided in a limited manner. Given the constraints imposed by high stakes examination, the government could start by introducing more flexibility in the education system to enable and encourage students to take Science and contrasting subjects.*

While many governments promote STEM education under the premise of shortages of innovative human capital for sustaining productivity and growth, the argument for universal STEM education should be based on the fact that STEM literacy is important for everyone working and living in an increasing technology-centric and a globalised world.

- Technology is now made available and accessible to individuals to not only enjoy but also to harness as tools in ways that contribute to the good of oneself and of all beings. On the other hand, technology advancement also means that more and more mundane or labour-intensive jobs could be replaced as automation takes its place. A society needs to equip its people with more STEM knowledge and skill in order to understand and embrace the technologies around us and to utilise them for the good of mankind.
- STEM literacy is important to allow citizens to participate in the debates of many global issues that require good understanding of how science works. Issues such as global warming and environmental protection vs economic growth; genetically-modified food vs food safety; the ethical debate behind the use of embryonic stem cells as well as cybersecurity and privacy, etc.
- A STEM-literate society will enable its citizens to make good personalised decisions about their lives that will benefit the society as a whole. For instance, a good understanding of food nutrition or what constitute healthy lifestyle would go a long way to help suppressing the medical bill that is increasing as the population ages. An understanding of the carbon footprint of our daily life activities could also help sustain a healthy environment.

- STEM-knowledgeable people therefore need not be a scientist but should be able to understand, evaluate and take advantage of the vast amount of science and technology information available to further their personal goals and improve their well-beings. They should be able to participate and contribute to debates and public discussions of various social issues involving science and technology. This requires an understanding of how scientific knowledge is generated and validated and the pros and cons in the applications resulting from using the knowledge. Last but not least, the aim of universal STEM education is to stimulate students' interests in the physical world in order that they appreciate the wonders of nature, human discoveries and inventions.

Delivery of STEM education

The world's education systems, especially at the secondary school level, are responding to the rapid technological changes in society by designing the best programmes for the next generation of the 21st Century. Debates are rife over "STEM for all" or "STEM for the advanced cohorts" through tracking or specialist schools¹¹. Proponents of the former camp, which include the United States, Continental Europe and supporters of the International Baccalaureate programme, argue that the primary goal of science education is to provide a broad overview of the major ideas that science offers of the material world and about the way science works to all students in order to make them "critical consumers of scientific knowledge" (J. Osborne & J. Dillon, 2008). The latter school, which is supported by the United Kingdom and many Asian countries, focuses on the importance of producing high-performing STEM cohorts in society.

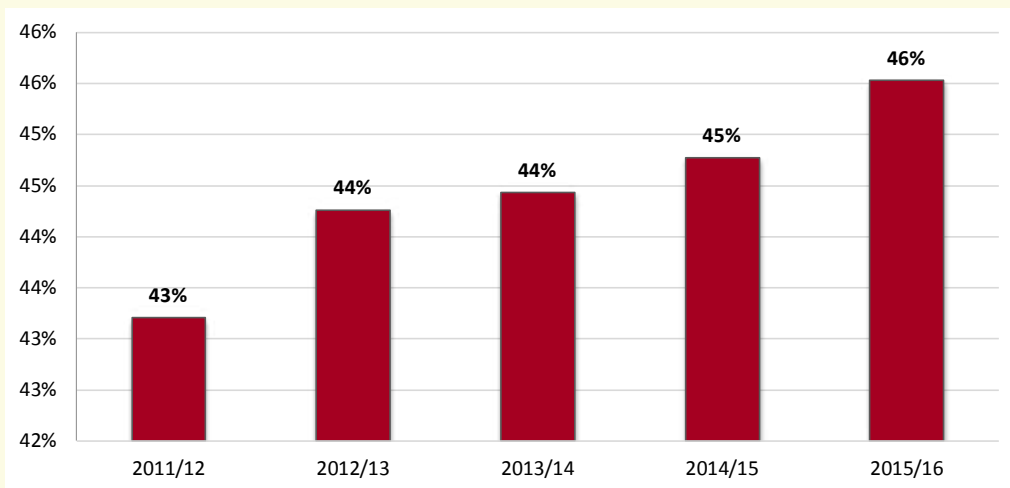
Nonetheless, despite the differences, the twin goals are not mutually exclusive. Most countries agree that engaging all students with STEM and enhancing high-performing STEM cohorts in the secondary school level are important, even though their focus and strategies may differ. For the former camp, module flexibility is emphasised via offering advanced level curricula alongside basic level syllabus while, for the latter, STEM is made compulsory for all students up to upper secondary level before specialisation takes place.

As part of the educational reform, Hong Kong has shifted away from the UK system to adopt the broad-based US education system, with three years of study at senior secondary, followed by a four-year-degree study at universities or two-year sub-degree study at post-secondary institutions. The tracking system at senior secondary level was abolished with the aim of promoting holistic or whole person development. Under the new system, students can choose their electives across Science and Humanities electives. It is expected that, without tracking, the artificial boundary between Arts and Science will disappear.

¹¹ Examples include Super Science High Schools in Japan, Science and Arts Schools for the Gifted in Korea, National University of Singapore High School of Mathematics and Science, Singapore School of Science and Technology, and Australian Science and Mathematics School.

The reality however, is quite contrary to expectations. Over five years of the HKDSE between 2012 and 2016, around half of the HKDSE students did not take any Science or Technology subjects (Chart 1)¹². This ratio is only slightly better than the 60:40 split between Arts vs Science¹³ students under the old HKCEE system when tracking was in place, but far below the science enrolment in the US and many other countries. This means that although Hong Kong has aimed to migrate to a liberal, broad-based education for all, the broadening of STEM education has not been achieved.

Chart 1: Percentage of HKDSE candidates who did not take any Science subjects, 2012-2016



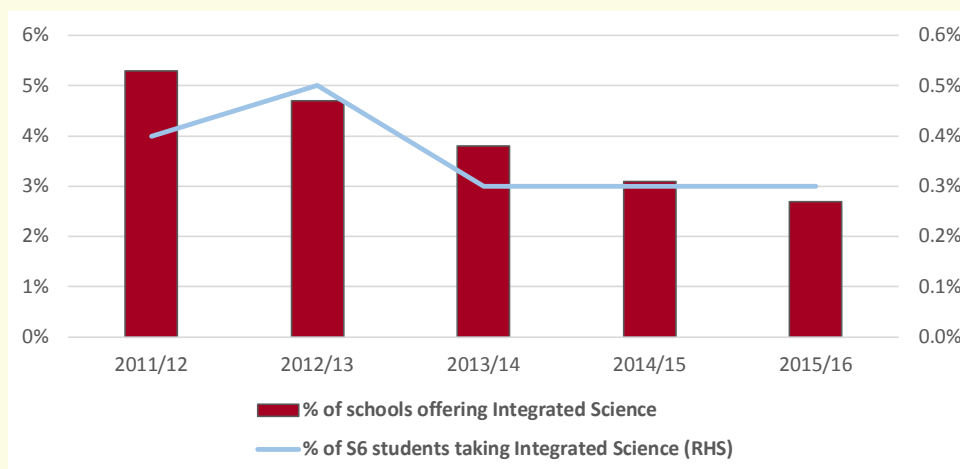
Source: Hong Kong Examinations and Assessment Authority, 2016

In order to entice the non-Science students to study some form of science, the Education Bureau offers an Integrated Science elective, which adopts an interdisciplinary approach to provide a broad overview of key science ideas and explanatory frameworks of science. However, provision and participation rates are low. In 2016, only 2.7% of secondary schools offer that elective and the enrolment rate is only 0.3% (Chart 2).

¹² Science or Technology subjects here include Biology, Chemistry, Physics, Integrated Science, Combined Science and Information and Communication Technology.

¹³ "Science" students are measured using percentage share of day school candidates who sat for Physics test in Hong Kong Certification of Education Examination in 2010. The actual ratio was 41.2%.

Chart 2: Integrated Science - % schools offered and % S6* students who took the course in 2015/16



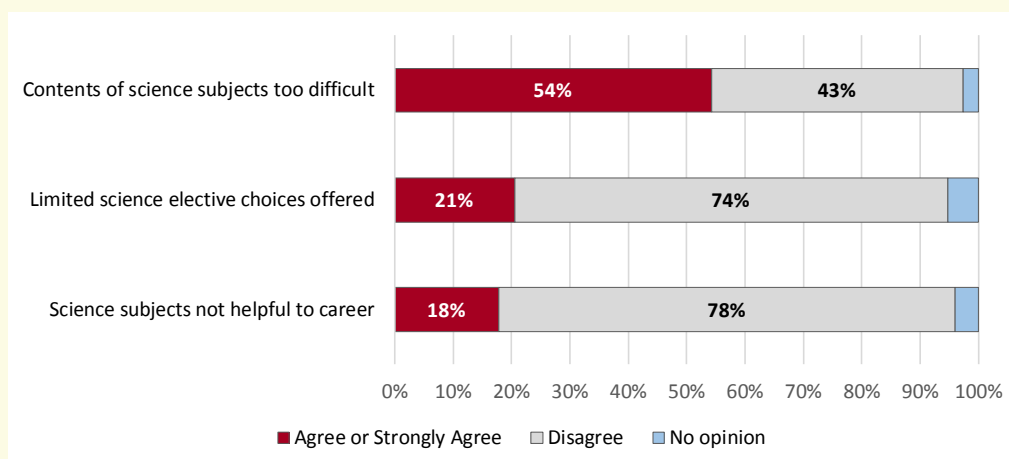
*Secondary 6 student enrolment information is extracted from the HKDSE Examination registration information on schools that participate in the survey.

Source: Survey on Senior Secondary Subject Information, Education Bureau. Secondary 6 student enrolment information is extracted from the HKDSE Examination registration information on schools that participate in the survey.

When asked why so many students do not take any Science subject, 54% school respondents agree or strongly agree that “contents of science subjects being too difficult for arts-oriented students, causing negative impact on examination scores” is a reason behind it (Chart 3). About a fifth (21%) believe that it is due to “limited choices offered by schools for arts-oriented students” and 18% believe it is due to lack of career prospects. Finally, some suggested it is due to lack of interests.

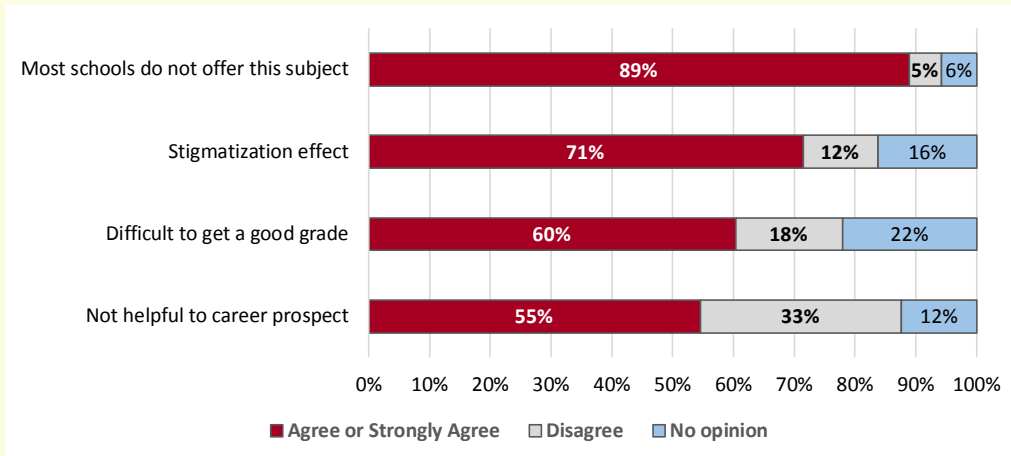
As to why student enrolment of Integrated Science is low, the respondents believe the reasons include: 1) “that most schools do not offer this subject (89% respondents agree or strongly agree); 2) that it cannot provide adequate basic science training to students and students are concerned about stigmatisation effect” (71%); 3) “difficult to get a good grade” (60%) and; 4) “that the subject is not helpful to career prospects” (55%) (Chart 4). Regarding the reason why schools do not offer the subject, some respondents explain that most teachers are discipline-based and hence not trained to teach multidisciplinary classes.

Chart 3: "Why do you think most students do not take any Science Elective?"



Source: Survey on STEM education, The Academy of Sciences of Hong Kong, (Oct, 2016)

Chart 4: "Why do you think few arts-oriented students take Integrated Science?"



Source: Survey on STEM education, The Academy of Sciences of Hong Kong, (Oct, 2016)

Science and Mathematics in broad-based education systems: force and choice

In many countries, Science and Mathematics are compulsory subjects for upper secondary students (Chart 5). Indeed, cross-Arts-Science study is part and parcel of many broad-based education systems that aim at offering a balanced and holistic training to students.¹⁴ In the US, for example, all high school students are required to study Science and Mathematics, among others, for graduation. Although the US education system varies among states with different emphasis and requirement for different subjects, all states require students to take English language, Mathematics, Social Studies and Science as part of the core curriculum. (Chart 6). Using a 10-state average as a proxy¹⁵, US high school students are required to take at least three credits (one credit is a one full course that normally runs for a year) from Science subjects and three credits from Mathematics during their four-year-study. Many states specifically required the three credits to include Biology, plus one other physical sciences.

¹⁴ In many countries, students are given choices among many Science subjects, including for example, Physics, Chemistry, Biology and Earth Science, which are also offered in various modules such as Basic/Compulsory and Advanced/Electives, to which they are required to choose at least a certain minimum amount in order to qualify for Secondary School graduation. Students are free to opt for more courses should they want to build depth of knowledge. The same principle applies to Arts subjects.

¹⁵ The 10 states are selected based on the following criteria: 1) US Census Department's breakdown of the country into 9 regions; 2) the most populous state of each of the nine regions; 3) inclusion of the US capital, District of Columbia.

Chart 5: Compulsory subjects for senior secondary education among countries with no science-arts-discipline streaming

	Language 1	Language 2	Math	Science	One or more subjects
IBDP	●	●	●	●	●
Australia	●				
Canada	●	●	●	●	●
Estonia	●	●	●	●	●
Finland	●	●	●	●	●
Germany	●	●	●	●	●
Hong Kong	●	●	●		●
Japan	●		●	●	●
Korea	●	●	●	●	●
Netherlands	●	●			●
New Zealand					
Sweden	●	●	●	●	●
USA	●		●	●	●

Note: ● Compulsory

Source: Nuffield Foundation, International Baccalaureate

Chart 6: Standard high school graduation requirements in the United States (10-state)^

Carnegie Units*	English Language	Math	Social Studies	Science	Others	Total
California	3	2	3	2	3	13
Texas	4	3	4	3	10	24
New York	4	3	4	3	8	22
Florida	4	4	3	3	10	24
Illinois	3	2	2	2	7	16
Massachusetts	4	4	3	3	8	22
Arizona	4	2	3	3	8	20
Tennessee	4	3	3	3	7	20
Missouri	4	3	3	3	11	24
Washington DC	4	4	4	4	8	24
Average	4	3	3	3	8	21

^ The 10 states are selected based on the following criteria: 1)US Census Department's breakdown of the country into 9 regions; 2) the most populous state of each of the nine regions; 3) inclusion of US capital, District of Columbia

*One Carnegie unit is one full course (usually one year of study or 120 hours of student hours)

Source: Education commission of the States; <http://ecs.force.com/mbdata/mbprofall?Rep=HS01>

Likewise, International Baccalaureate Diploma Programme (IBDP), a two-year programme that prepare students for tertiary education with no tracking, also makes studying Science and Mathematics compulsory. Under the system, students are required to take at least one Science subject, one Humanities subject, two languages, Mathematics, one other elective and a Theory of Knowledge in order to graduate. The same is true for Finland, where students are required to take a minimum of 75 courses (38 lessons of 45 minutes each) in order to graduate from upper Secondary general education. That includes 45-51 compulsory courses that span across a wide range of subjects, including both Science and Humanities (Chart 7).

Chart 7: Finland's upper secondary schools' course distribution

	No. of Courses*
Compulsory courses	45-51
Mother tongue & literature	6
A-language	6
B-language	5
Mathematics	6-10
Environment & Science	5
Humanities & social sciences	11
Arts, crafts & sports	4-6
Specialization course	Minimum 10
Applied courses	
Total	Minimum 75

* Each course has 38 lessons of 45 minutes each

Source: Finnish National Board of Education

Module flexibility and freedom of choice of electives to cater for student diversity of aptitude and interests

There are two important factors why the US, IBDP and others could make cross-Humanities-Science-study a reality: 1) module flexibility within subjects to cater for students' learning diversity and; 2) freely elective subjects. Module flexibility entails the offering of simple and advanced level programmes for all or major subjects for students to choose. It allows students to both specialise on their major areas of strength and interests while also making it possible for them to *broaden* their knowledge with a contrasting and less demanding subject for whole-person development hence achieving a "T-shaped" education of breadth and depth of knowledge. Freedom of subject choices, on the other hand, is the hallmark of the non-tracking system whereby students can freely choose any subject across science, humanities, vocational and other applied learning activities. It aims at promoting a student-centred learning process in order to enhance engagement and performance. When combined with the mandatory requirement for cross-Humanities-Science study, these two features, among others such as flexible modular approach for study and assessment, provide the necessary flexibility and diversity within the system.

In the US, for example, advanced level courses such as Honours or Advanced Placement programmes are provided as options in subjects including English, Mathematics, Chemistry, Biology, Physics, History and Civic Studies as well as in some electives such as Accounting and Information Systems. Students are free to choose either version per subject to graduate although many universities make it clear they would like to see students taking challenges during their high school study. In IBDP, students are required to take three "Standard Level" and three "High Level" among the total of six subjects in the curriculum, on top of the Theory of Knowledge paper. The latter has the added benefit of eliminating potential stigmatisation effects that come with simpler syllabus choices. Finland, on the other hand, breaks down its courses into a compulsory part for each major discipline as well as specialisation courses for students to develop depth (Sahlberg, 2013)¹⁶.

¹⁶ Modular curriculum structure is adopted only for the general upper education of Finland, which prepares students for universities.

In contrast, under the tracking systems, students' learning diversity is handled by screening and filtering that nonetheless narrows students' learning opportunities. In the UK, for instance, students who failed to pass the GCSE¹⁷ are screened out from the academic track, although module flexibility is recently introduced for those who could continue into post-16 (of age) schooling. In Europe (including Finland), on the other hand, students are also divided into academic and vocational tracks, some at the early part of the upper secondary education (Chart 8). However, for the non-vocational, general upper education courses, module flexibility is offered.

Chart 8: Examples of flexible module arrangement by countries with no arts-science-streaming

Course offered	Basic level	Advanced level
IB Diploma	Standard Level (SL): 3 subjects	High Level (HL): 3 subject
US	Core: optional	Honors / Advanced Placement: optional
Canada (Ontario)	Applied, College, Workplace: optional	Academic, University: optional
Germany[^]	Basic courses: 3 courses	Advanced courses: 7 courses
Finland[*]	Compulsory courses: 45-51 courses	Specialization courses: minimum 10 courses
Denmark[*]	Level C (for Compulsory and Specialized)	Level A and B (for Compulsory and Specialized)
HK	DSE: (10th-12th). No options, except Math	

[^] German Gymnasium, Rhineland-Palatinate, Nuffield Foundation, Towards Universal Participation in Post-16 Mathematics: lessons from high-performing countries

^{*} Refer to general upper secondary education only

Source: Finnish National Board of Education, International Baccalaureate, US National Centre of Education, Ontario Ministry of Education, UK Department of Education, Ministry of Children, Education and Gender Equality, Denmark

Hong Kong: No mandatory requirement and limited choices of cross-Arts-Science study

In Hong Kong, although Mathematics is compulsory, Science subjects are optional for senior secondary students in the HKDSE. They are known as Electives, and not as part of the "Core" curriculum. Neither is cross-Humanities-Science study mandatory in the HKDSE, as in other broad-based, non-tracking, education systems. In addition, module flexibility is offered only in Mathematics but not in other subjects in HKDSE. Finally, although choices are offered for Electives, the combinations in individual schools vary and are highly concentrated among a few subjects (see Chapter 3), while some schools even provide only a limited number of subject choices for students.

Below are structural constraints that hinder Hong Kong from practising a full-fledged STEM-for-all strategy; some of them are reflected in responses from stakeholders in our survey. They include: 1) inadequate teaching and physical resources; 2) the lack of scale of our schools; 3) an oversized "Core" curriculum that leaves little room for Electives, and; 4) the existence of high stakes examination that lead to risk aversion among students, parents and schools. The discussion below focuses on the resources, scale and high stakes in examination whereas the issue of Core versus Electives will be addressed in Chapter 3.

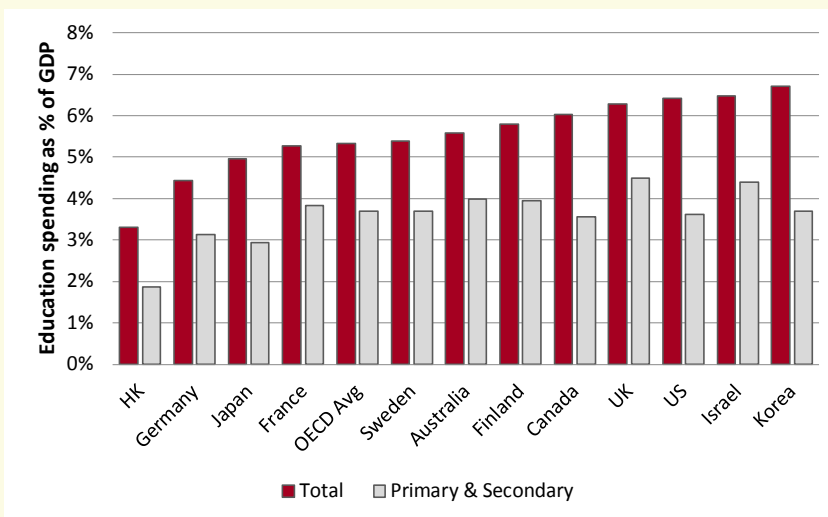
¹⁷ GCSE: The General Certificate of Secondary Education is a secondary school leaver qualification awarded in UK.

1. Inadequate teaching and physical resources

The provision of module flexibility and subject choices come with costs, as more teachers and teaching support¹⁸, classrooms and physical infrastructure, syllabuses designs and assessment work are required. For example, if students are genuinely allowed free choices in their modules and electives, it is unavoidable that some subjects would be much more popular than the others, so classrooms of various sizes, as well as flexible timetable and possibly multiple timeslots for same subject, will be required. This would create pressure on both the physical and software infrastructure of schools. Module flexibility may also imply more work on assessment, which in other countries, are supplemented by flexible examination schedules.

While data on Hong Kong's upper secondary education are not available, Hong Kong's overall spending on education is low, at 3.3% of GDP, compared to OECD average of 5.3% (Chart 9). Spending on primary and secondary education amounts to only 1.9%, compared to OECD average of 3.7%. On a per student basis, government spending per secondary school student amounts to 17% of per capita GDP for Hong Kong in 2012. This is much (32%) lower than OECD average of 25% (Chart 10). For example, in Finland, a country touted as the model of quality education with high emphasis on teachers' quality and small class teaching, also offers module flexibility and full elective choice freedom, achieve good results at the expense of costs. Spending on primary and secondary education, at 3.9% of GDP, is more than double that of Hong Kong.

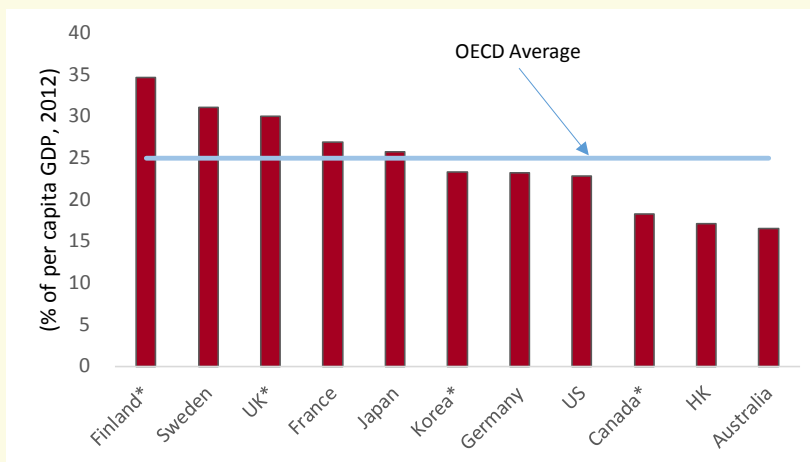
Chart 9: Comparison of public education spending



Source: OECD Education at a Glance 2015, Education Bureau, The Government of the Hong Kong Special Administrative Region

¹⁸ Teaching resources in secondary schools is a controversial issue. According to the Government, our teacher-student ratio of 12.2 is comparable or even better than the OECD average of 13.5 (OECD, 2014). In addition, class size has fallen to 29 (2015/16) and will continue to decline as student population drops over the next couple of years. Many stakeholders however argue that the current ratio is inadequate to enable schools to cope with student learning diversity.

Chart 10: Government expenditure per secondary school student



* 2011 data for Canada, Finland and UK. 2013 data for Korea.

Source: World Development Indicators

2. Lack of Scale

Among financial considerations, scale is critical to ensure spending efficiency. In Hong Kong, however, our secondary schools do not have the scale that their counterparts in countries like the US enjoy. The average number of senior secondary students per grade in Hong Kong’s schools is far less than that in the US, at 116 compared to 251 (46%¹⁹) (Chart 11). In addition, student population is expected to drop further by 25% over the next few years before gradual recovery to about 85% of the number for 2015 (Chart 12). As mentioned above, physical and software infrastructure is required for schools to provide flexibility for students’ choice of elective subjects, a small school with limited number of classes and classrooms will find it difficult to offer choices. As a result, students in some secondary schools in HK, especially the ones with less financial resources, are classroom-bound. Instead of allowing the students to choose their elective subjects freely, in some cases it is the schools that offer “pre-set menus” for students to choose due to the administrative considerations.

Chart 11: Comparison of average size of secondary schools

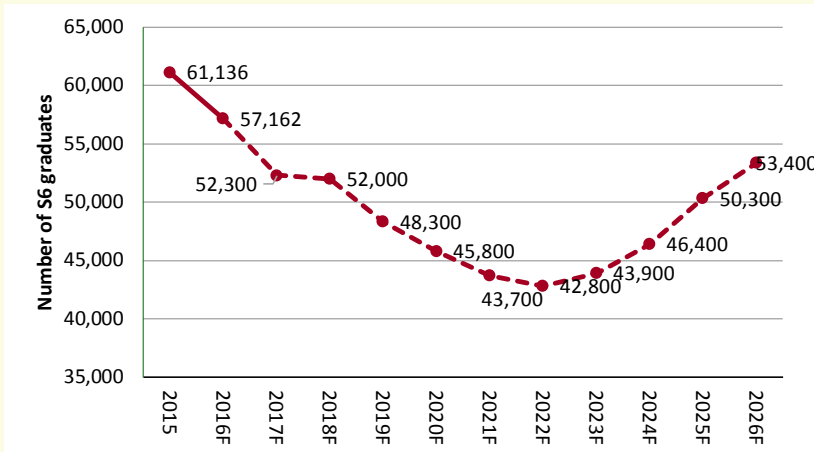
	HK*	US	Finland
Average no. of upper secondary school students per school	697	752	262
Average no. of years of study	6	3	3
Average students per academic year per school	116	251	87

* Total number of secondary school, instead of upper secondary school students for Hong Kong

Source: Education, Statistics Finland (2015), Education Bureau, Hong Kong, National Center for Education Statistics, US

¹⁹ Due to a difference in education systems, the number in the US refers only to that of the upper secondary schools.

Chart 12: Declining student population



* F: Forecast

Source: Hong Kong Examinations and Assessment Authority and Education Bureau, Hong Kong

It is however noteworthy that flexibility can also exist in systems with small school sizes. Finland, for example, with a population of only 5.5 million, has one of the more flexible education systems in the world in terms of how classes are organised and sequenced as well as the amount of choices available to students (Ruzzi, 2005). There are no specific grades or year-long classes so students can graduate in less than or more than a three-year period. Under Finland's modular approach, students have to finish a minimum of 75 courses consisting of 38 lessons of 45 minutes each. This modular approach is gradually being adopted by other countries including the US and Canada. Besides the scale advantage, a modular approach has the additional benefits of relieving examination-related stress, as students have freedom to choose and adapt their study (and examination) schedule according to their aptitude. Such a modular approach thus calls for a different philosophy in curriculum design, which is still foreign to most parents, students, schools and the Government in Hong Kong.

3. High stakes in examination narrow students' learning

Finally, the socio-economic and cultural context of a country is likely to bear an impact on social acceptance towards making Science compulsory to all students. A major difference between US, Finnish or other continental European education systems and that of Hong Kong lies in the high stakes in our examinations. In countries like the US, Finland, Canada and Sweden, mandatory cross-Arts-Science education is not linked to public examinations for tertiary selection. In the US, for example, university admission is based on a standardised aptitude test (SAT), school assessment and other non-academic assessments, and is not directly linked with the credit system required for high school graduation. In Finland, although students are required to study more than 12 subjects, they are tested on four (no more than five) subjects in their matriculation examination. In many other systems where public examinations for tertiary selection do exist as in Hong Kong, examination stress is somewhat alleviated by: a) high provision rate of university places; b) high social acceptance towards vocational training as an alternative pathway or; c) less inequality among income levels, as measured by the Gini coefficient (Chart 13).

Chart 13: Potential factors affecting high stakes examination and social acceptance of Science being a compulsory subject

	External examination used for senior secondary certification	External examination used for tertiary selection	Institutional entrance examination	Standardized test of aptitude/achievement	School-based assessment	Selection information other than ability assessments	Tertiary education attainment 2015 (%) ¹ (age 25-34)	Vocational education attainment 2015 (%) ² (age 25-34)	Gini Coefficient ³	Science being compulsory subject at senior secondary ⁴
Australia (NSW)	●	●			●		38	25	35	N
Canada						●	34	12	34	Y
Denmark ⁵	●	●			●		40	33	29	Y
England	●	●				●	41	21	33	track system
Finland	●		●				41	41	27	Y
France	●	●	●				28	36	33	track system
Germany	●	●			●		30	59	30	Y
Hong Kong ⁶	●	●			●		32/14	14	54	N
IB Diploma	●	●			●		n/a	n/a	n/a	Y
Japan			●				40	n/a	32	Y
Sweden	●			●	●		35	27	27	Y
United States				●	●	●	37	21	41	Y

1 OECD (2016) "Education at a glance: Educational attainment and labour-force status"

2 OECD (2016) "Education at a glance: Educational attainment and labour-force status". Share of 25-34 age cohorts with at least upper secondary education attainment, including vocational training

3 The Gini coefficient measures the inequality among values of a frequency distribution (for example, levels of income). A Gini coefficient of zero expresses perfect equality, where all values are the same (for example, where everyone has the same income). A Gini coefficient of 1 (or 100%) expresses maximal inequality among values (e.g., for a large number of people, where only one person has all the income or consumption, and all others have none, the Gini coefficient will be very nearly one). Source: World Bank, Hong Kong Government (for Hong Kong only)

4 Nuffield Foundation, "Y" denotes Yes, "N" denotes No

5 Science is compulsory for 1/2 year out of the 2.5-year-program for Denmark.

6 32% is calculated using 2011 Census data on population with highest education attainment of degree or postgraduate degree. That would include degrees obtained overseas and part-time self-financed degree courses. 14% is calculated using only first-year student intakes of UGC-funded programmes between 1999/00 and 2008/09 over population of age 25-34 as of mid-2015. Vocational education attainment rate includes population with craft level education, matriculation (incl. technician level) and post-secondary Diploma and Certificate

Source: Doug McCurry, 2013, Overview of Senior Assessment and Tertiary Entrance in Australia and other countries (for data related to tertiary admission only)

In Hong Kong, however, senior secondary education is directly linked to the HKDSE, which accounts for 80-85% of scores that are primarily used by universities in their student selection process. Although the government figures show that 32% of the 25-34 age cohort has attained a university bachelor or higher degree, only 14%²⁰ of the age cohort is estimated to have enrolled into UGC-funded programmes. Intense competition for UGC-funded degree programmes is a major cause of examination stress. In addition, compared to the Continental European countries, vocational track is not highly valued in Hong Kong (or in many Asian societies) as a viable alternative pathway. Finally, Hong Kong has one of the highest Gini coefficients among OECD countries or regional peers, which aggravates the stress to succeed via examination. The above are merely some of the factors that underline the high stakes in our examination system, which is a highly complex subject that requires further research.

Many studies, however, have pointed out that the high stakes in examination has led to “teach-to-test” and “study-to-test” practices among teachers and students and their unintended consequences such as the narrowing of curriculum and of students’ learning (Nicholas, 2007) (Yeh, 2006) (Amrein, 2002). In Hong Kong, it is generally acknowledged that most students will not be serious in studying a subject if it is not required in tests. Instead, they will concentrate on the few subjects that are known to be included in tests in order to achieve high scores. Should Hong Kong students be required to take cross-Arts-Science subject examination for university entrance, there are concerns that it will impose a huge workload on them as it is recognised that the expected “synergy” of studying contrasting subjects in an examination-based assessment system would be low. Therefore, the mentality of score maximisation for university admission prevails over the aim of general education, making it difficult to implement cross-Arts-Science education.

Moving forward

While high stakes in examinations will persist in the local education system, given the need for Hong Kong to compete globally, we should consider creating a favourable condition to enable and encourage students to broaden their horizons by taking contrasting subjects as a short-and-medium term remedy. The solution includes the provision of flexibility and diversity in subject and syllabus choices, while both module flexibility and additional freedom of choices for Electives may be introduced, along with adequate provision of resources as well as an overall mind-set change among all stakeholders.

Our survey of school principals found that 66% of respondents disagree with requiring students to take cross-Arts-Science studies, citing the need to respect students’ choices and to cater for divergence in aptitude and interests. However, in the question regarding how to reduce workload of students in the Core curriculum, 60% agree or strongly agree that “cater for students’ learning diversity, offer basic level and advanced level syllabus” is an effective way to do so to make room for students to take more Elective subjects. (See Chapter 3). These survey results have led us to believe that besides the Core curriculum, module flexibility may

²⁰ The total number of places in UGC-funded universities is set at 15,000 per year, which corresponds to roughly 18% of students who sit for the HKDSE each year. The number cited here refers to the percentage of age-cohort, to allow apple-to-apple comparison with other countries.

also be gradually introduced into the Electives in order to enable and encourage more students to take a contrasting elective to broaden their horizon. While this proposed measure may be a far cry from achieving the aim of STEM-for-all, it can be a step in the right direction of addressing concerns that current science curricula are too difficult for arts-oriented students.

Module flexibility is feasible in Hong Kong as traces of this can already be found within the current system. In curriculum design, most HKDSE syllabuses are divided into two parts: a Compulsory and an Extended Elective section; the former accounts for around 60-80% of the total teaching hours and the latter is also designed to cater for diversity of interests. An expedient way to create a simple or basic level module out of the existing curriculum is simply to take the Compulsory part or trim down existing curriculum, to say around 60%, as is done by the International Baccalaureate Diploma Programme (IBDP). In IBDP, a Standard Level (SL) module accounts for 62.5% of the guided learning hours of a High Level (HL) module.

Module flexibility can also be seen in the assessment of the current English test, which has two different papers for students to choose, Part A and Part B, which offers a glimpse of how one can treat scores from different modules. The simple module, Part A, can attain a maximum of only Level 4 in the HKDSE examination while the more advanced module, Part B, allows a maximum score of Level 5**²¹. In other systems (such as IBDP or Finland), however, there is no difference in grading for different modules as the mixed module is either embedded in the system or universities will specify the level of modules required for specific subjects in their admission requirements.

“Cross-Arts-Science study helps broaden the knowledge base of students and enhance science literacy. However, contrasting subject also entails risks to students in their DSE examination, making them reluctant to take the course. Suggest introducing basic and advanced level syllabuses on Electives to students ... to raise their level of confidence towards taking a contrasting subject,” a secondary school principal responded to the ASHK survey on STEM education.

²¹ Under the HKDSE, test scores are divided into 7 grades: Level 1, 2, 3, 4, 5, 5* and 5** with 5** being the highest.

Recommendations:

STEM literacy for all. Science education should be made available and be encouraged to all students as understanding of the natural and physical world and how science works is essential to one's work and living in the 21st Century. A STEM literate society could also support the transition of Hong Kong into a knowledge-based economy and to contribute to global effort to combat climate, environmental and aging demographics issues. To ensure a broad-based and holistic development of our students, cross-Arts-Science study should be promoted at senior secondary schools in Hong Kong.

- ***Coping with student diversity of aptitude and interests.*** Module flexibility and freedom of subject choices are essential to complement the provision of Science, Technology and Mathematics education to all senior secondary students. Module flexibility can be experimented by stages, starting with the Core Subjects, to be extended over time to a few other major Electives. One option to consider is to carve out a portion, say 60-65% of the existing subject syllabi, comprising the major concepts of the subject as the compulsory core or “basic level” syllabus. The advanced level module would include extended topics and/or greater depth of some topics. Assessment of the different modules can be modelled after the current English paper, whereby the basic syllabus can attain a maximum of Level 4 while the advanced module can attain the highest Level of 5**. Finally, module flexibility is best complemented with flexibility in the assessment system.
- ***Enabling resources to allow student-centred subject choices.*** Adequate financial resources are needed to enable our schools to offer more subject choices via the hiring of teachers as well as expansion or refurbishment of school facilities. In addition, choices should be offered on a free, rather than pre-set basis to ensure student-centred learning and address learning diversity. With more resources, schools should be encouraged to adjust timetable management to ensure more free choices are available to students. As the number of school-age students is expected to decline over the next few years, this may be an opportune time to make the necessary adjustments to the curricula of the HKDSE.
- ***Universities admission. Universities' admission strategies have a strong bearing on students' subject choices.*** In the face of the high stakes in examination, students are risk-averse to taking broad and contrasting subjects. To encourage students to build a balanced knowledge foundation, universities are encouraged to consider giving incentives to students to take more Science, Technology and Mathematics subjects as part of their entrance requirements and in calculating admission scores.

Other suggestions:

- **Innovative science curriculum and pedagogy.** Ample research on STEM education (Singer, 2012) (Kober, 2015) has shown that engaging students into inquiry-based study and collaborative scientific investigations and discussions are effective ways to improve conceptual knowledge and attitudes about learning. Therefore, engaging curricula and innovative ways of delivering STEM should be explored with the aim of making learning science interesting. Curricula for STEM literacy should focus on fewer disparate factual information but need to bring together key scientific ideas in a coherent manner that highlight their relevance to daily lives, modern technologies and the environment and should cover topics of interests to both boys and girls.
- **Extra-curricular STEM education.** STEM learning should not be limited to classrooms and should be enhanced by extra-curricular activities such as student-driven inventions, on-the-field learning, trial work experiences out of schools and trial learning and mentorship experiences at universities. In addition, science exhibitions, technology symposiums and public science lectures and competitions are ways to stimulate and inspire students' interests. Stakeholders from the business and start-up community, universities, the Government and other advocacies for STEM education should work together to create STEM learning opportunities for students. To encourage schools and students to participate in more of these activities, the current academic curriculum needs to be trimmed to create room for out-of-class learning experiences.
- **STEM teachers.** Teachers play a crucial role in stimulating students' interests and facilitating their learning. Delivering innovative science curriculum and pedagogy requires that teachers be acquainted with updated scientific knowledge as well as latest technologies in related fields. Continuous professional development should expand beyond the scope of traditional half-day seminars to more comprehensive training that allows teachers a wider range of STEM-related exposure and networking with the business, technology and scientific world.
- **Full integration of STEM into education.** As STEM is but one integral part of the education system, any changes recommended in this report should take into account the broad picture of curriculum structure and processes as well as the synergy between formal and non-formal learning for students. In addition, besides senior secondary curriculum, the whole secondary and even the primary school curriculum (albeit not covered in this report) need to be reviewed, including Primary General Studies and Junior Secondary Science.
- **Promotion of STEM literacy by public media.** As the public media play an important role in reporting new discoveries in science and new invention in technology, they can help in educating the public and raise the STEM literacy of the community. When reporting on STEM-related news items, instead of just focusing on the sensational aspects, brief accounts by ways of the basic scientific concepts and the potential benefits to society at large should be covered. It should also be considered a corporate social responsibility for academics, R&D professionals, innovation and technology entrepreneurs and related entities to work with the media to bring the latest information to the public.

- **Vocational education of STEM.** STEM constitutes an important part of the vocational training education in Hong Kong²², a topic that is not covered in this report but is nonetheless highlighted by stakeholders as an area that deserves attention. This includes the introduction of innovative curricula that offer updated STEM skills that match the needs of the business world as well as in enhancing industry-school partnership. In addition, effort needs to be made to promote the study of Applied Learning at senior Secondary level²³.

²² According to data from Vocational and Training Council, student enrolment into STEM-related disciplines account for 45% and 42% of total High Diploma Programme intake in 2015 and 2014, respectively.

²³ Based on data from HKEAA, candidates who sat for one or more Category B subjects account for 5% of total DSE's day school first attempters in 2015 and 2016.

Chapter 2: Mathematics

Mathematics is the most beautiful and most powerful creation of the human spirit.

Stefan Banach

***Summary.** Compared to many countries, Hong Kong students have good performance and positive attitude towards Mathematics, as measured by PISA on 15-year-olds. However, such attributes do not translate into good take-up of advanced Mathematics at senior secondary schools. While an international survey conducted by PISA shows a high correlation between enrolment of Mathematics and perceived career prospects by students, our survey reveals that most school principals think the reasons for declining enrolment is due to the positioning of Module1/Module2 in the Mathematics curriculum, as well as lack of incentives from universities to encourage students to take the more demanding modules. The survey finds that boosting advanced Mathematics require strategies on both demand as well as supply side.*

As an important language of STEM, Mathematics is widely used in many science as well as non-science fields and improved mathematical skill is regarded as crucial in an increasingly technology-centric world.

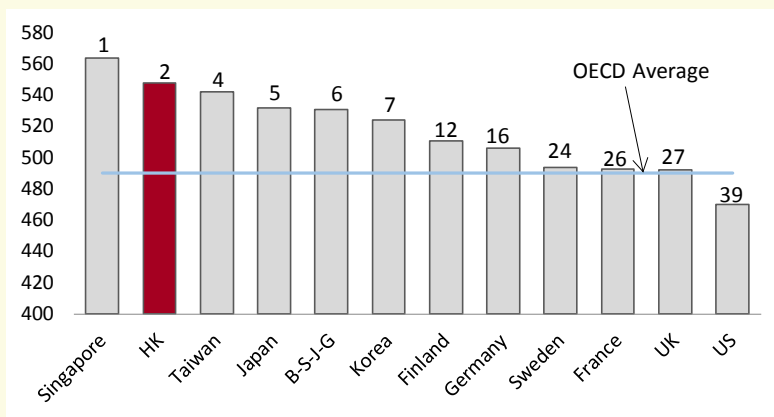
- Mathematics fosters logical and rigorous thinking which is essential to a knowledge based economy. As automation and technology threatens to take away low-skilled jobs, problem-solving skill, which is a major part of Mathematics, will become increasingly important.
- As the Internet opens up the potential of big data, new job opportunities arise in many fields that demand mathematical fluency and sophisticated skills to handle statistics, modelling and data analytics beyond what is being offered in most basic mathematics courses.
- The quantitative needs of many university courses are rising (Advisory Committee on Mathematics Education, 2011). Not only do some Science disciplines previously thought to be not so mathematically-centric, such as Biology and Medicine, demand higher level mathematical skill but other non-science programmes such as Social Studies, Business Management and even History increasingly recognise the importance of statistics and mathematical modelling.

Mathematics education in Hong Kong

High achievement of mathematics in primary and junior secondary schools

Hong Kong has a good track record of performance in international assessment programmes where it has garnered top ranks over the last decade. For instance, in the 2015 PISA test on Mathematics for the 15-year-olds, Hong Kong ranks second, with an average score that is 12% higher than the OECD average (Chart 14). In the TIMSS Mathematics test on 4th grade and 8th grade students in 2015, Hong Kong ranks second and fourth, respectively (Chart 15). Not only are the average scores high but the distribution of student performance is also good. In the 2015 PISA Mathematics tests, less than 10% of Hong Kong students fall into the “low achievers”²⁴ group while over a quarter of our students belong to the “top performers”²⁵ group (Chart 16). These impressive achievement, which has been maintained for over a decade²⁶, suggests that Hong Kong students have a solid foundation in the subject.

Chart 14: Mathematics PISA Score (2015)



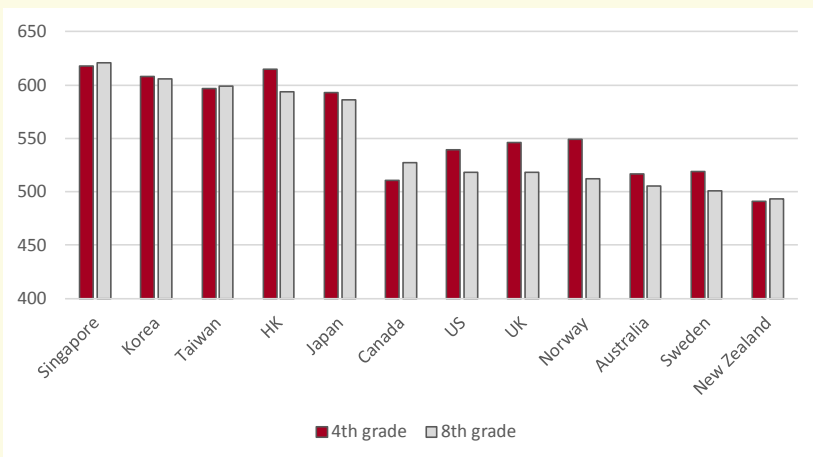
Source: OECD, PISA 2015 Database

²⁴ Student performance is graded into six levels with Level 1 being the lowest and Level 6 being the highest; “low achievers” include students below Level 2. Source: OECD, PISA

²⁵ Student performance is graded into six levels with Level 1 being the lowest and Level 6 being the highest. “Top performers” include students of Level 5 and 6. Source: OECD, PISA

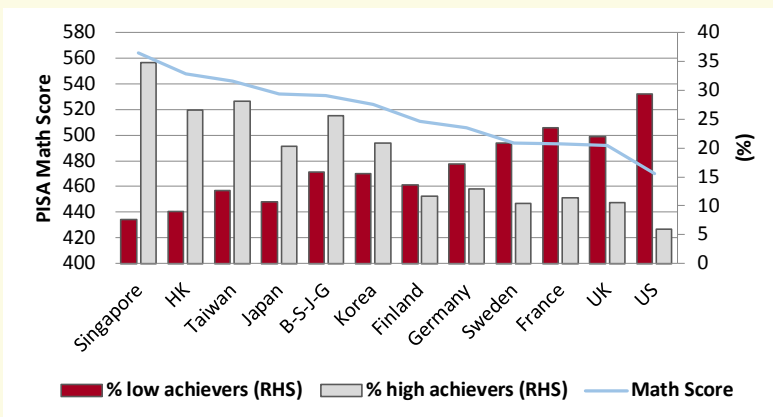
²⁶ Hong Kong ranked first, fourth, third and third in the 2003, 2006, 2009 and 2012 PISA Mathematics tests respectively, and third, fifth, third and second in the Science tests for the same period

Chart 15: TIMSS Mathematics Score (2015)



Source: TIMSS (2016)

Chart 16: PISA Math Score and Low/High Achievers % (2015)

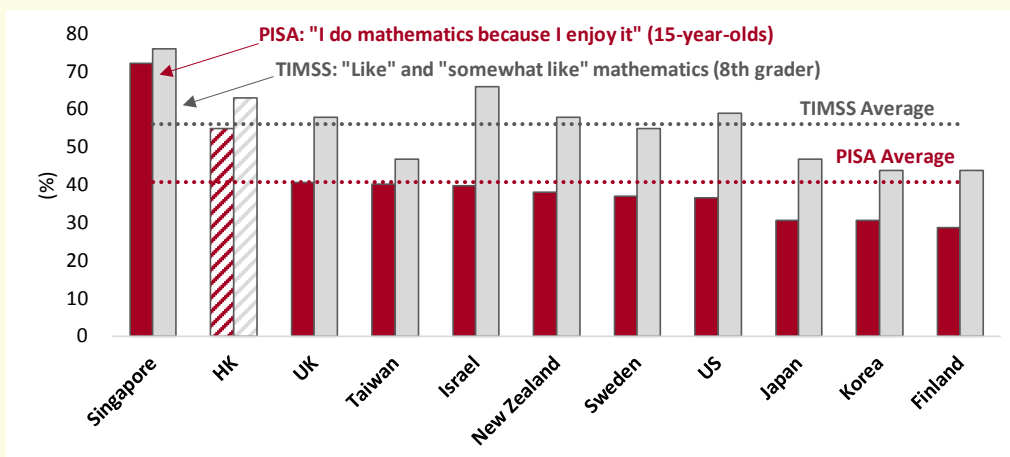


Source: OECD, PISA 2015 Database

Positive attitude

Besides high achievement, Hong Kong students show a positive attitude towards Mathematics, as compared to the OECD and regional peers. Surveys conducted by PISA (2012) for the 15-year-olds and by TIMSS for the 8th graders (2015) show a high percentage of students responding positively to whether they like Mathematics or whether they do Mathematics because they enjoy the subject (Chart 17). This positive attitude stands in contrast to some other high-performing countries such as Korea, Japan, Finland and Taiwan, indicating a harmonisation and probably a reinforcement of student motivation and attainment.

Chart 17: Student attitude towards Mathematics



Source: OECD, PISA 2012 Database

Basic Mathematics made compulsory in new senior secondary education

The reform of the senior secondary education in 2009 made Mathematics compulsory as one of the Core Subjects, alongside Chinese Language, English Language and Liberal Studies. In a way, it is an extension of the old practice under HKCEE whereby Mathematics is mandatory for all students; whether they be in the Arts or Science stream. In another way, however, including Mathematics in the Core Curriculum can be regarded as a major breakthrough because students under the old senior secondary education were not required to take Mathematics when they prepared for A-Level or AS Level examinations. With the new measure, Hong Kong has joined the global community whereby Mathematics is compulsory in upper secondary or vocational education (Chart 18).

Chart 18: Countries where Mathematics is mandatory in upper secondary or vocational education

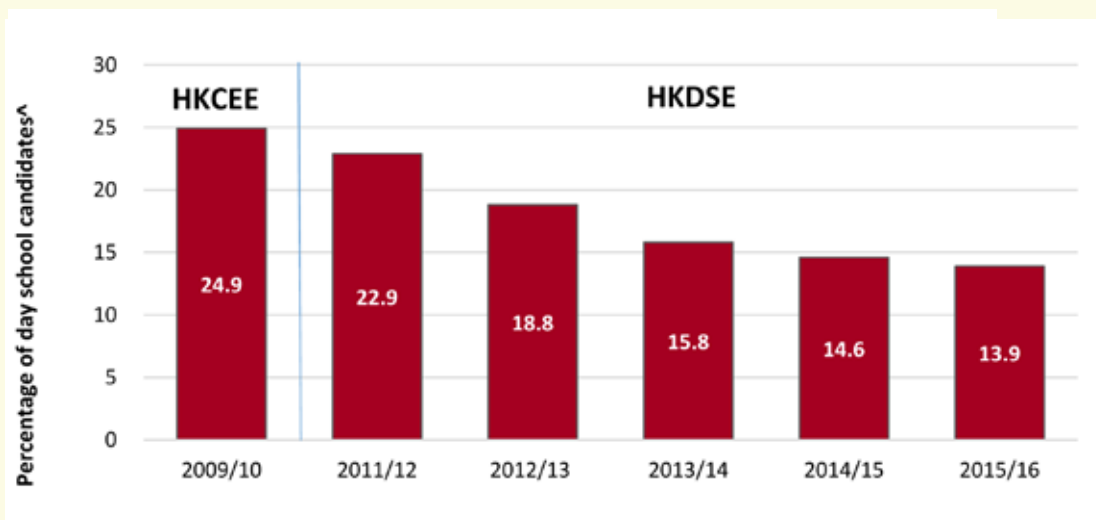
Is Mathematics compulsory?	
Australia	No
Canada	Yes
Czech Republic	Yes
Estonia	Yes
England	No
Finland	Yes
France	Yes
Germany	Yes
Hong Kong	Yes
Hungary	Yes
Ireland	No
Japan	Yes
Korea	Yes
Netherlands	No
New Zealand	No
Russia	Yes
Singapore	Yes
Spain	No
Sweden	Yes
Taiwan	Yes
USA	Yes

Source: Nuffield Foundation

Low take-up of advanced Mathematics

The problem, as most would surmise, lies in advanced Mathematics, which is offered only as extended modules: Module 1 (Calculus and Statistics) and Module 2 (Calculus and Geometry), in addition to the basic Mathematics under the Core Subjects of the HKDSE curriculum. It does not stand on its own as a full subject either in the Core or as an Elective. Since the beginning of the new senior secondary system, enrolment rate of M1/M2 has dropped continuously from 23% of the initial cohort in 2011/12 to below 14% in 2015/16 (Chart 19).

Chart 19: Enrolment of advanced Mathematics*



* Additional Mathematics for 2009/10 under the HKCEE system

[^] % of Day School First Attempters for 2009/10 and % of all Day School students for 2011/12 and afterwards.

Source: 2011/12 to 2015/16 HKDSE data, for schools and students, are sourced from The Survey on Senior Secondary Subject Information, which could be slightly different from the entry statistics prepared by HKEAA. 2009/10 HKCEE data are directly sourced from the entry statistics in the report prepared by HKEAA and only refer to Day School First Attempt students

Under the old HKCEE system, advanced Mathematics is offered to students in the form of Additional Mathematics, and, for students in matriculated studies for A Level or AS Level examinations, in the form of Pure Mathematics and Applied Mathematics. In 2010, 25% of HKCEE candidates took Additional Mathematics and around 25% of Hong Kong A-Level students, or less than 10% of age cohort enrolled into Pure Mathematics or Applied Mathematics.

Using students taking Physics as a proxy to Science students under the HKCEE system, around 60% of Science students took Additional Maths in 2009/10. As a contrast, only 34% of the “hard core” Science students, defined as students who took two or more Science Electives in the HKDSE, took M1/M2 in 2015/16, while only 12% of candidates who took one Science subject opted for M1/M2.

While an enrolment rate of 10-14% in advanced Mathematics for senior secondary school is low by international standards, the problem becomes more pronounced when the HKDSE school leavers enter universities. In the past (under the HKCEE system), those university programmes that require a strong mathematical foundation are able to admit A Level graduates with an advanced Mathematical background as well as students who have at least taken Additional Mathematics in Forms 4 and 5. Under the current HKDSE, universities often encounter students with only basic mathematical training (as provided in Mathematics of the Core Subjects),

which is insufficient to cope with the quantitative aspects of many university courses. In short, there is no more buffer. This deficiency in mathematics among university freshmen in most Science and Engineering programmes necessitates the introduction of remedial or developmental programmes in the universities to close the gap. Unfortunately, one additional foundation year in universities cannot easily replace the two or more years of proper learning in the secondary school level. If nothing is done to deal with the problem, the situation will get worse because the universities may be forced to take in even more unprepared undergraduates when the student population in Hong Kong continues to drop over the next few years.

Policy development and implementation, as always, carries unintended consequences. In some way, the drop in advanced Mathematics enrolment in the HKDSE relative to that of HKCEE's Additional Mathematics reflects a "trading down" phenomenon similar to the introduction of AS levels in the UK, which saw a large drop in the number of students taking A Level Mathematics in 2002. (J. Hodgen, 2013). The recovery, as in the case of UK, took almost a decade in which universities' admission strategies play a critical role to drive back students' engagement.

Low participation rate relative to peers

Hong Kong's 14% participation rate in advanced Mathematics is clearly low, compared to 25-80% for our regional peers, many of whom are also high performers in international assessment tests (Chart 20). Globally, this number also makes Hong Kong among the bottom in advanced Mathematics enrolment (Chart 21). The high enrolment rates of some countries, such as Korea, Taiwan and Japan, may be explained by compulsory requirement of advanced Mathematics for entrance to most science and engineering programmes in universities or are mandatory for high school study, but countries like Singapore and New Zealand achieve high participation with no compulsion.

While only a quarter of the then-Hong Kong A Level students took advanced Mathematics in Hong Kong (2010 figure), the figure was 80% for Singapore. (J. Hodgen, 2013). Mathematics is regarded as a highly respected subject in Singapore. In addition, Singapore requires all A Level students to take a contrasting subject (J. Hodgen, 2013) and students in arts may choose between advanced Mathematics and science for their non-arts subject.

Chart 20: Advanced Mathematics' take-up in Asia Pacific

	% of upper secondary age cohort	PISA Math 2012 Ranking
Hong Kong	14% ¹	3
Japan	80%	7
Korea	57%	5
New Zealand	40%	22
Singapore	39%	2
Taiwan	67%	4
Australia	25%	19

¹ 2016 data for Hong Kong from HKEAA for HKDSE students only. Data for age cohort is not available but the difference is not expected to be significant.

Source: Data for New Zealand, Scotland and Singapore: J. Hodgen et al., (2013) Towards universal participation in post-16 mathematics: lessons from high performing countries, Nuffield Foundation.

Data for Japan, Korea, Taiwan: J. Hodgen et al., (2010) Is the UK an outlier?, Nuffield Foundation

Chart 21: Advanced mathematics take-up in selected developed countries globally

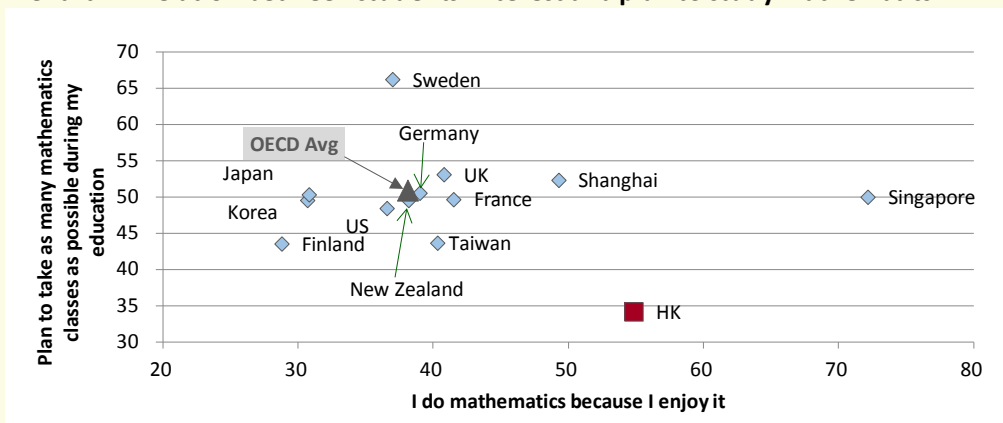
High (30-100%)	Japan, Korea, Taiwan, Singapore
Medium (15-30%)	Estonia, Finland, Germany, New Zealand, Sweden, France, US (Massachusetts), Australia (New South Wales), Scotland
Low (0-15%)	Russia, Ireland, Netherlands, Hong Kong*, Spain, UK (ex Scotland)

* Hong Kong's data is adjusted for HKDSE 2016 results. Source: Education Bureau, Hong Kong

Source: "Mathematical Needs - Mathematics in the workplace and in Higher Education" published by Advisory Committee on Mathematics Education, UK

Career concerns

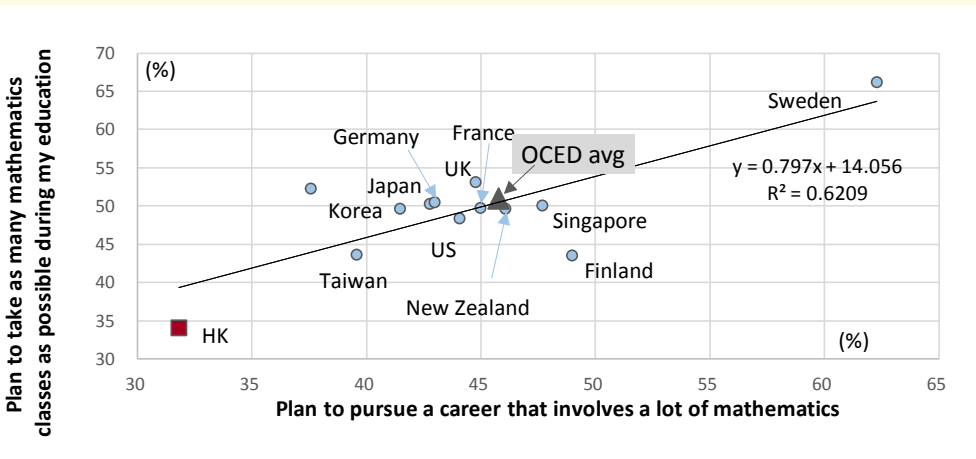
A global survey conducted by PISA in 2012 on students' attitudes towards Mathematics highlights the dichotomy between student interest and subject decision. Although a high percentage of Hong Kong students say they "do mathematics because they enjoy it", few of them plan to take more Mathematics (Chart 22).

Chart 22: Relation between students' interest and plan to study Mathematics

Source: OECD, PISA 2012 Database

In addition, data from the same survey shows a high correlation between career consideration and subject choices among the 15-year-old high school students in different countries/regions. As illustrated in Chart 23, students who say they "plan to take as many Mathematics classes as possible" are highly correlated to those who state that they "plan to pursue a career that involves a lot of Mathematics". Indeed, when compared to the OECD and regional peers, Hong Kong is on the low end of the distribution, which indicates strong student reservation over career prospects relating to the study of Mathematics.

Chart 23: Relation between students' career consideration and decision on Mathematics study



Source: OECD, PISA 2012 Database

The low take-up rate for advanced Mathematics may be explained by the small share of manufacturing in Hong Kong vis-à-vis other OECD countries or regional peers (Chart 24). In the US, for instance, manufacturing accounts for 12% of gross domestic product (GDP) and, for 69% of total US business R&D spending in 2013 with an R&D intensity ratio of 10.5%, compared to 1.9% GDP share of total business spending on R&D (US government statistics). According to OECD, manufacturing industry is the most technology intensive industry among developed economies and is the major driver behind innovations and business R&D (OECD, 2010). Hong Kong's weak manufacturing base limits the career prospects of engineers as well as scientific researchers. In addition, the small domestic market hinders the growth of knowledge-intensive industries such as computer and software engineering, which often require a large and sophisticated home market to scale up.

Chart 24: Share of manufacturing as % of GDP



* 2012 data for New Zealand

Source: World Development Indicators, CEIC.

Finally, as the financial hub of Asia, Hong Kong does offer attractive prospects for quantitative financial analysts and actuarial jobs. However, no data on these or other STEM-requiring jobs are available in Hong Kong, making it difficult to analyse and project on jobs availability and earning differential between jobs requiring STEM-training and those that do not. In the US, for example, the government has tabulated and released historical data and 10-year projections on jobs that require STEM knowledge and median wage by education qualifications, in order to attract students to take up studies of STEM subjects.

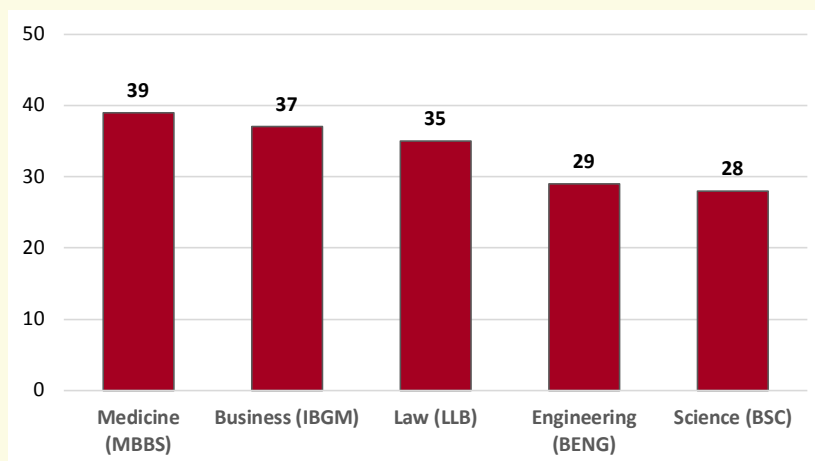
To attract more students to studying advanced mathematics in an increasingly data-centric world, countries such as New Zealand have restructured their Mathematics curriculum to cater for students with different career and study pathways. An option that focuses on mathematical fluency, statistics, modelling and the application of mathematics is introduced, on top of traditional advanced mathematics that prepare students for higher education courses in Engineering, Science and Mathematics. This is credited as the reason behind the country's high participation in advanced Mathematics (J. Hodgen, 2013). As Big Data proliferate into many facets of our daily life, data application and analytics will become essential to many fields such as Business Management, Social Studies, Biosciences, Psychology and other areas that were previously not regarded as mathematics-intensive. Therefore, curriculum developers must be cognisant of such trend in the global market and extend the appeal of advanced mathematics to a wider group of students.

University admission

Besides career prospects, students are influenced by universities' admission requirements and guidance in making study decisions. "Students study what universities tell them", is a general remark we heard from many secondary school principals. In our survey, 76% of respondents agree or strongly agree that "not recognised or required by some UGC-funded universities for admission" is a reason why fewer students are willing to take M1/M2. Out of the eight UGC-funded universities, only four recognise M1/M2 as an elective in general entrance requirement and some recognise them in individual programmes.

In general, universities over the world and their degree programmes are guided by two main factors in their admission policies. One is the balance between supply and demand for their degrees, which is shaped by external factors such as economic structure and career prospects for different degree holders; the supply of degrees is also influenced by market factors as well as government policies. The second over-riding factor is the university's specific admission strategy. Some highly sought-after programmes choose to adopt a "filtering out" strategy by setting a high requirement at the onset to filter out unqualified students. Some, however, opt for a "catchment" policy whereby universities set low entrance requirements in order to "catch" as many students as possible. The latter is not an option in Hong Kong as student numbers for individual degree programmes in universities are governed by the University Grants Committee. In Hong Kong, owing to the weak job prospects in science and technology-related R&D positions in commercial companies or in the manufacturing industry, many high-performing students opt to study university degrees in medicine, business and law, which are considered to offer more attractive career prospects. Using data from The University of Hong Kong as an example, students admitted to those three disciplines, medicine, business and law, have scores that are much higher than those admitted to the science and engineering programmes (Chart 25). The difference in median entrance scores hence reflects the demand/supply balance of the individual faculty, which underlines its bargaining power in setting admission criteria.

Chart 25: Admission scores of HKDSE applicants admitted by HKU in 2015



Source: The University of Hong Kong

To identify the driving factors behind our university admission policy with respect to advanced Mathematics, we look at the relationship between entrance score and their admission criteria for programmes that require advanced mathematics. First, the median entrance score is compiled as a proxy index of the bargaining power of the individual degree programmes. Second, the admission strategies are graded into “demanding” and “incentivising” ones. Demanding strategies include setting M1/M2 as prerequisites or setting high minimum attainment level and “incentivising” ones include strategies such as stating that the subjects are “preferred” or “recommended”, by giving bonus weighting in score calculation and/or by recognising M1/M2, as full Electives.

As shown in Chart 26, the engineering faculties of three universities all score low in their relative median entrance index and have tried different ways to attract candidates to take M1/M2. The strategies include recognising the half Modules as full Electives, giving bonus weighting or preference to candidates with M1/M2. None of them makes M1/M2 a prerequisite for admission, however. In contrast, for programmes in Quantitative Finance, which commands a higher entrance score/bargaining power, see two out of three universities that offer the programmes made M1/M2 a prerequisite for admission. Besides Quantitative Finance, Actuarial Study and selected enrichment programmes in Sciences at some universities, have both a high median entrance index score and the privilege to have a high entrance requirement for M1/M2.

Chart 26: University entrance score and admission strategy on advanced Mathematics

	Median Entrance Score Index*	High marks Required	High marks required#	Prefer / Recom	Bonus	Full elective
Engineering:						
University 1	0.91	XX		●	X	●
University 2	0.78	XX		●	●	●
University 3	1.05	XX		●	●	●
Quantitative Finance^:						
University 1	1.04	●	XX		X	●
University 2	1.12	●	XX		X	●
University 3	1.00	XXXX				●

● Positive, X Negative

*Relative to the Median Entrance Score of Bachelor of Business (ex Global Business). For those with no general admission score, simple average of various departments in the relevant faculty is used

^ Actual name of programme will be different among universities

Some overseas universities set grade level prerequisite in admission on Advanced Mathematics (see Chart 27)

Source: The Hong Kong University of Science and Technology, The University of Hong Kong, The Chinese University of Hong Kong

In short, amid intense competition for student enrolment, although some Faculties are fully aware of the deficiency in advanced Mathematics training among their students, they are unable to drive higher M1/M2 requirements because they are facing an unfavourable supply and demand problem. To overcome this imbalance, it would be necessary for the universities to build collaboration or some sort of alliance among themselves to push for the requirement of advanced Mathematics for certain programmes and to state explicitly the kind of mathematical training required (or preferred) for the senior secondary students.

While admission policies vary from university to university, some top universities globally offer incentives or set prerequisites for students to study advanced Mathematics. In the US, for instance, some universities grant transfer or test credits to students who have achieved certain scores in advanced Mathematics programmes such as Advanced Program. In the UK, major Science programmes of top universities state explicitly they require high score in A Level Mathematics (or equivalent) from applicants (Chart 27).

Chart 27: University recognition policies on advanced Mathematics

University	Admission policies on advanced Mathematics
Oxford	A-Level Mathematics with score of A*/A or IB High Level at scores of 6 or 7, or equivalent is required for students applying for Chemistry, Computer Science, Earth Sciences, Engineering, Materials Science, Mathematics, Statistics, and Physics
Cambridge	All colleges offering Chemical Engineering, Computer Science, Engineering and Economics require a 6 or 7 score in IB High Level or A* or A at A-Level
MIT	12 units of credits on Calculus I are given for students who score 6 or 7 in IB's Math HL, or 4 or 5 on BC Calculus of Advanced Placement or grades above B at GCE A level
Stanford	8-10 credits are given to students who score 5 on AP Calculus AB or BC, 10 credits are given to IB's Math HL with score of 6 or a maximum of 12 credits to GCE students on subjects which receive College Board AP Credit
University of California, Berkeley	4 credits are granted for students who score 3 or higher on AP Calculus AB and 8 credits for Calculus BC, 8 credits for IB High Level students who scores 5, 6 or 7
Caltech	No credit transfer are granted
Harvard	No credit transfer are granted for AP or other examinations

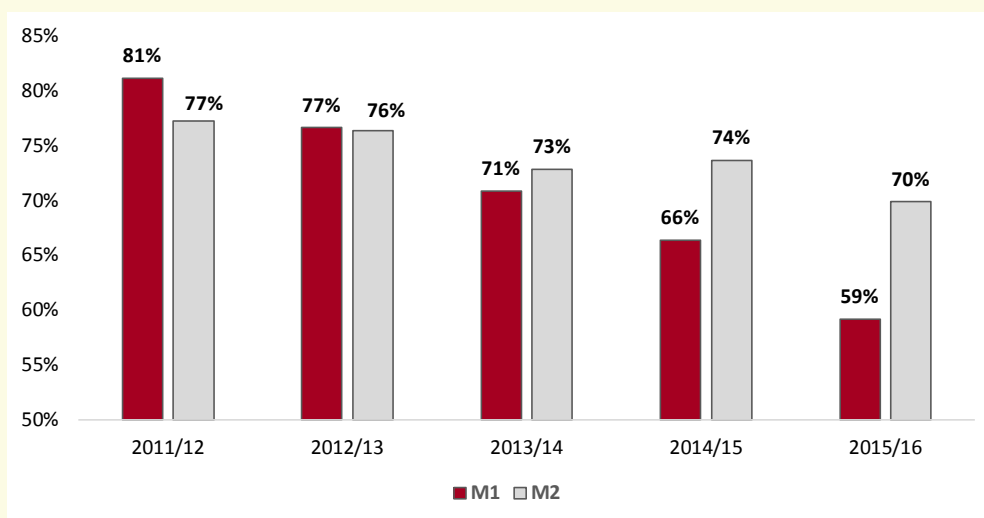
Source: Oxford University (2016), Cambridge University (2015), Massachusetts Institute for Technology (2016), Stanford University (2016), University of California, Berkeley (2016), California Institute of Technology (2016), Harvard University (2016)

The above is very unlike the practice in some local universities, where a broad, faculty-based admission policy is adopted with a uniform admission requirement across programmes and students are allowed to declare their major in the second year. While this flexibility may help some students who have not decided on their majors to choose faculty-based admission, it also helps build enrolment figures. Unfortunately, it might have also sent blurring signals to students on specific requirement of Mathematics for certain degree programmes. For instance, the need for advanced Mathematics is much higher for Chemistry than for Biology, yet there is no difference in the admission requirement. Likewise, the need for advanced Mathematics is much more demanding for Economics than Business Studies but they share similar admission requirements.

Schools provision and curriculum design

Low participation in advanced Mathematics in Hong Kong is correlated with low provision among the secondary schools, but it is unclear which one is causative. A Survey on Senior Secondary Subject Information shows that along with the drop in enrolment, school provision of M1/M2 has also been in a decline in the past few years (Chart 28). Provision of Compulsory Part of Mathematics and M1, for instance, fell from 81% in 2011/12 to 59% in 2015/16. That with M2, on the other hand, also drop, albeit more moderately from 77% to 70% over the same period.

Chart 28: Secondary Schools' provision of M1/M2



Source: Survey on Senior Secondary Subject Information (2016), Education Bureau, Hong Kong

There may be two reasons why schools do not offer or have low incentives to offer advanced Mathematics classes under the HKDSE. One concerns students' learning capacity and examination scores. Given that M1 and M2 are relatively more demanding, some schools apparently direct their students to focus on Mathematics in the Core, in order to have more time and resources for other subjects. Indeed, HKDSE results do show that for students who take either M1 or M2, the majority of them see their scores for M1/M2 being at least one grade below what they score for Mathematics in the Core (Chart 29).

Chart 29: Level distribution of day school candidates in Mathematics Compulsory Part and Extended Part of 2016 HKDSE

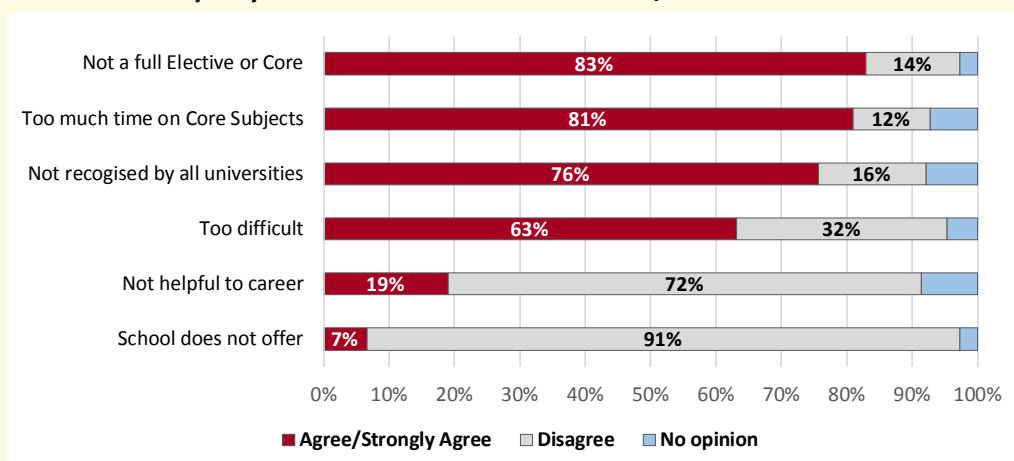
Grade	Attainment in Core Mathematics % of day school candidates	Attainment in M1/M2		
		Candidates with same or better grade to Core Mathematics	Candidates with grades 1 level below that of Core Mathematics	Candidates with grades more than 1 level below that of Core Mathematics
5**	8%	26%	37%	38%
5*	20%	27%	40%	32%
5	26%	38%	39%	23%
4	36%	34%	34%	32%
3	8%	16%	34%	50%
2	2%	13%	42%	44%
1	0%	22%	78%	n/a

Source: Hong Kong Examinations and Assessment Authority, 2016

Second, even for schools offering M1/M2, many of them do so after school hours, given that most schools are stretched in their teaching hours (more discussion on this subject in the next Chapter). Moreover, M1/M2 are offered as extended modules of Mathematics, not as full Electives (outside of the Core Subjects). So unless universities stress the importance of M1/M2 in their admission requirements, the students' attitude towards M1/M2 is not going to improve. Currently, only four (to be five in 2017) out of the eight UGC-funded universities treat M1/M2 as 'Full Electives' but there are variations for different degree programmes. The latter discourages schools from paying due attention to M1/M2 and priority would continue to be placed on allocating adequate resources and time to satisfy the Core Subjects and a few key Electives. Consequently, M1/M2 will remain mostly after-school hour classes, especially for schools with fewer high-achieving students.

According to our survey (Chart 30), 83% of respondents agree or strongly agree that one key reason for the low and declining enrolment of M1/M2 is due to it being "not an HKDSE Core Subject or Elective". In addition, among the schools that offer after-school hour classes and provide us with subject details (see Chapter 3), 33% say that M1/M2 are among the top-three subjects that require after-school-hour training.

Chart 30: "Why do you think students do not take M1/M2?"



Source: Survey on STEM education, The Academy of Sciences of Hong Kong, (Oct, 2016)

Mathematics curriculum

Concerns have also been raised by stakeholders regarding the breadth and depth of our advanced Mathematics curriculum. Compared to others, such as the IBDP, UK's A-Level and Singapore, the advanced Mathematics curriculum of the HKDSE (i.e., M1/M2) is much narrower in scope. This is in contrast with other subjects, where most stakeholders would like to see a more focused coverage on fewer topics. (This will be discussed in Chapter 3).

Extended Module 1 (Calculus and Statistics) and Module 2 (Calculus and Algebra) each cover two strands in moderate to intensive depth, supplemented by basic level of Algebra, Geometry and Trigonometry, which are designed for art-oriented students. Experts argue that the HKDSE is much narrower in breadth and depth than, say, the IBDP or Singapore programmes, each of which has four modules that cater for different aptitude and interests of students with different study and career pathways. The high-level modules of the latter include a full suite of Algebra, Geometry, Trigonometry, Calculus, Pure Mathematics and Statistics (as in the case of IBDP) (Chart 31). Further, all these modules are offered alongside the basic and intermediate modules for students to choose as part of their respective core curriculum.

Chart 31: Comparison of Mathematics curriculum

	Algebra & Functions	Geometry	Trigonometry	Statistics	Calculus	Pure Math	Applied Math
IBDP							
Math Studies SL	moderate	moderate	2/5	6/8	2/13	2/8	
Math SL	All	incl. parametric equations & curves	4/5	5/8	8/13	2/8	
Math HL	All	incl. parametric equations & curves	5/5 1 new + All, prerequisite	8/8	11/13	5/8	
Math Further	All, prerequisite			8/8	12/13	6/8	Decision Math
Singapore A level							
Basic							
H1	moderate			7/8	6/13	0	
H2	All	incl. parametric equations & curves	All; pre-requisite	7/8	9/13	4/8	
H3	All	incl. parametric equations & curves as pre-requisite	All; pre-requisite		10/13	5/8	
UK's A Level							
A Level	All	incl. parametric equations & curves & polar coordinates	5/5	6/8	8/13	3/8	
Further Math	All; pre-requisite		All; pre-requisite		9/13	6/8	

* Denotes coverage. 2/5 means covers 2 out of 5 topics, as defined by the author

Source: L Bergeron, (2015), IB Mathematics Comparability Study: Curriculum & Assessment Comparison

Given the financial constraints and the weak business ecosystem of Hong Kong, it is nevertheless feasible to introduce module flexibility in Mathematics, even as one of the Core Subjects. This would introduce minimal administrative burdens. Should M1 and M2 be reclassified as alternative forms of Mathematics among the Core Subjects and due recognition and incentives be given by universities, it is believed that schools will divide their classes according to students' preference and needs. For example, in a school with four classes, two classes may be allocated for basic Mathematics, one for M1 and one for M2. This will help raise the overall enrolment of advanced Mathematics in Hong Kong. Alternatively, treating M1 and M2 as separate (full) Electives may also give incentives to schools and students to choose the subject.

Recommendations:

Improved mathematical skills are essential in an increasingly technology-centric world beyond the traditional boundary of science and engineering. To prepare the society with STEM talents as well as to cope with the rising needs in Statistics, Modelling, Data Analytics and Application, we need to raise student enrolment in advanced Mathematics. To extend the appeal of advanced Mathematics to a wider group of students and to encourage school provision, we believe it is important to give proper recognition to advanced Mathematics. At the same time, universities' admission offices should explicitly spell out the needs of various types of mathematical skills and give clear guidance and incentives to students while making their subject choices.

- **Give due recognition to advanced Mathematics.** To entice students and schools to give proper attention to advanced Mathematics, M1 and M2 should not be treated as extended Modules of a Core Subject but, as in many other countries, should be given a “full subject” status. In addition, module flexibility should be offered to cater for students with different study and career pathways.

1. One option is for the HKDSE to provide three alternative modules for Mathematics as a Core Subject. It should include a module for arts-oriented students; one for students who intend to pursue advanced education or career in business and social studies that require high mathematical fluency and a full-fledged advanced Mathematics programme for those who aim to pursue a career or further study in Science, Engineering and/or Mathematics. Under this option, the university admission offices must produce clear guidelines and/or incentives on specific module required for their relevant degree programmes.

2. Another option is for the HKDSE to offer basic and advanced syllabi for Mathematics as a Core Subject (as discussed in Chapter 3 for the other Core Subjects and Electives) to achieve Mathematics literacy as well as some level of numerical fluency for all students. Under this option, M1 and M2 would be introduced as full Electives (which may also offer basic and advanced syllabi), for students who aim to pursue a career of further study in Science, Engineering and/or Mathematics.

- **University driver.** Universities play an important role in driving student engagement in advanced Mathematics. To ensure that students have adequate prior knowledge and skills required to study certain Science, Engineering, Computer Science and other mathematics-intensive degree programmes, faculties as well as individual departments should specify the level and extent of Mathematics required to enrol in these programmes. To minimise vicious competition for students in the face of an unfavourable demand and supply balance of STEM jobs, universities may find the benefits of joining forces to set a higher standard, to give due recognition and incentives in order to raise the overall enrolment in advanced Mathematics in Hong Kong.

- **Relevance of mathematics, science and technology in career planning.** Mathematical skills of problem-solving and logical thinking, which can also be acquired from other science and technology subjects in general, are useful

to a wide range of STEM-related as well as non-STEM-related jobs. The value of STEM should be properly promoted to the business world and the STEM skills required at workplace should be conveyed to students with quality career counselling. Information and data on STEM jobs, including jobs availability, median income as well as past and forecast growth trend, should be made transparent and available to students. Finally, as part of the innovation and technology ecosystem, Hong Kong should take a holistic approach towards the promotion of STEM education as well as STEM career. This may require high-level, cross-bureaux policy coordination between the Innovation and Technology Bureau and the Education Bureau within the SAR government.

Chapter 3: Cross-discipline skills and knowledge

We are not students of some subject matter, but students of problems.

And problems may cut right across the borders of any subject matter or discipline.

Karl Popper

***Summary.** Multidisciplinarity is gaining importance in scientific innovation and research as well as in solving complex global problems and at workplace nowadays. In Hong Kong, over two-thirds of HKDSE candidates take only two elective subjects and over half of the candidates who have taken at least one Science subject, took only one Science elective. Our study finds that the major reason behind the narrowing of subject knowledge lies in an “oversized Core” that has taken up over 60% of the teaching time of most schools. Schools and students place high priority on the four Core subjects as they account for a large, 60-80% of the unweighted scores for university admission. There is an overwhelming consensus among stakeholders to trim down the Core in order to make room for students to take a third elective.*

Science and innovations of the 21st Century are trending towards multidisciplinary in a nature that requires not only specialisation in one field but also broad training across disciplines to enable collaborations and synthesis of ideas and minds. The rationale is that integration of perspectives, concepts, methodologies, data and culture of different fields is better positioned than unidisciplinary approach in the advancement of knowledge as well as in solving real world problems.

Over the past few decades, we have already enjoyed the fruit of some of these interdisciplinary inquiries. Examples include the discovery of the DNA structure, the invention of magnetic resonance imaging, radar, laser eye surgery, human genome sequencing, “green revolution” and manned space flight (National Academy of Sciences, 2005). In recent years, computational biology has developed into a major force behind cancer research. In addition, the advent of big data analytics in computer engineering have combined with brain and cognitive science to help advance artificial intelligence.

Universities, research institutions and research funding agencies all over the world are responding to the needs of interdisciplinary research. New topics of studies have emerged such as nanotechnology, genomics and proteomics, bioinformatics, neuroscience (National Academy of Sciences, 2005) and artificial intelligence; all of which demand interdisciplinary work.

Nor is multidisciplinary limited to Science. Many societal and real world problems demand collaboration of talents from hard and soft science as well as humanists to come up with solutions. Many of these problems are global in nature and cut across knowledge domains including terrorism, cybersecurity, globalisation of the finance and world markets, rising social inequalities, global climate change, etc.

Professionals would require multidisciplinary training in order to understand, communicate and connect with peers from other domains to solve such complex problems.

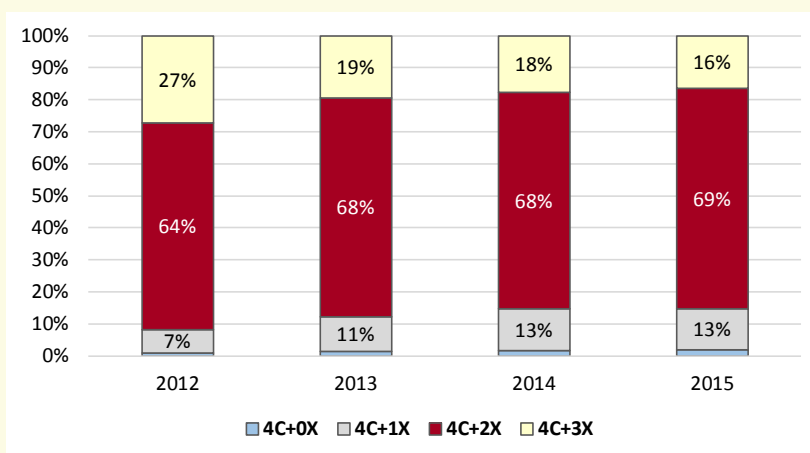
The drivers of interdisciplinary skills can thus be summarised as follows:

- Nature and society are inherently complex. Understanding the elements and forces within them requires examination from multiple disciplines.
- The advancement of technologies and knowledge have enabled new combinations of disciplines and approaches to solving old and new problems.
- As the world become more globalised, the complexities of problems grow exponentially. Solving societal problems would therefore require vast amounts of knowledge from different disciplines.

Multidisciplinary training under the HKDSE

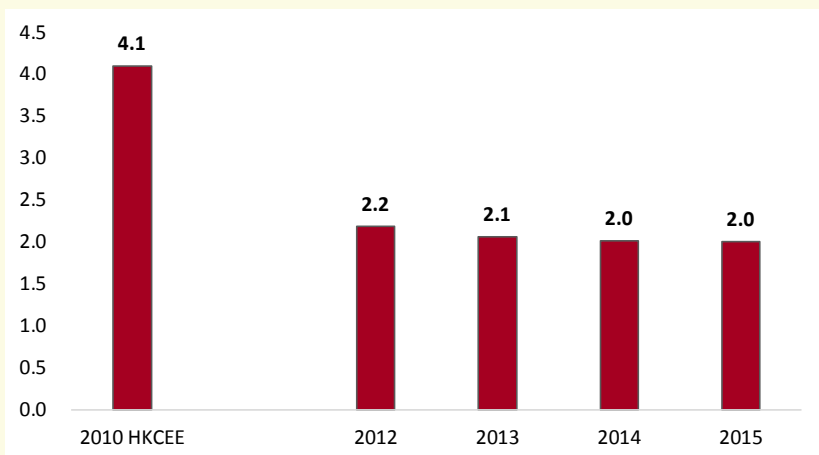
In Hong Kong, although the HKDSE allows students to take two or three Electives, on top of the four Core Subjects, most students opt for only two Electives (Chart 32). In 2015, over two-thirds, or 69% of students took two Electives and only 16% took three Electives; a drop from 27% in the initial cohort year of 2012. This participation rate is rather poor, when compared to the average of 4.1 elective subjects (in addition to Chinese, English and Mathematics) taken by students under the old HKCEE and 2.3 subjects at HK A Level students (other than English and Chinese) in 2010 (Chart 33). While the new HKDSE system places emphasis on languages, numeracy and civic knowledge, there are concerns that students' breadth of subject knowledge is too narrow. In the old system, specialisation at A Level comes only after receiving two years of broad education in Forms 4 and 5.

Chart 32: Breakdown of HKDSE students by number of subjects taken



Source: Hong Kong Examinations and Assessment Authority

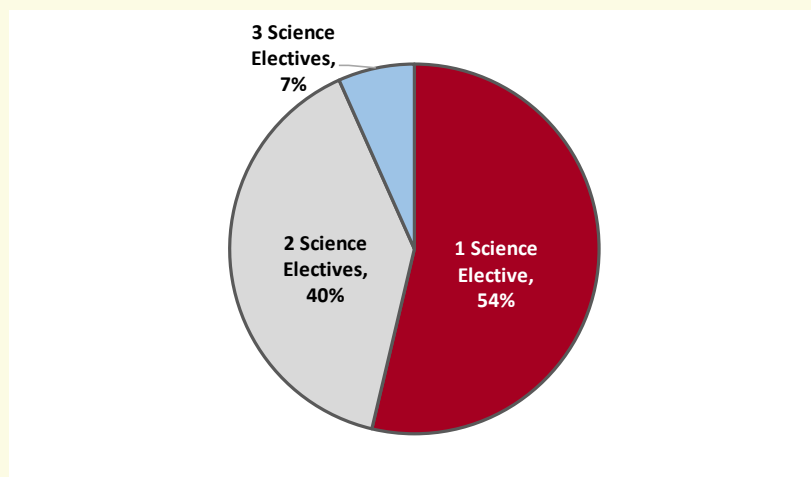
Chart 33: Compare average number of subjects under DSE and HKCEE, excluding Chinese, English, Mathematics and Liberal Studies



Source: Hong Kong Examinations and Assessment Authority

For Science subjects, while slightly over half (54%) of HKDSE students took at least one Science subjects in 2016 (for more details, see Chapter 1), the majority 54% (29% of total students) took only one Science subject, around 40% (21.6% of total) took two Science subjects and only 7% (3.6% of total) took three Science subjects (Charts 34 & 35). This is a big contrast with the old system when students were streamed into Arts and Science tracks. Under the HKCEE system, most Science students took three Science subjects; including Physics, Chemistry and Biology, on top of Additional Mathematics, while under the HK A Level system, most Science students specialised on two to three subjects including at least two Science electives, Pure or Applied Mathematics.

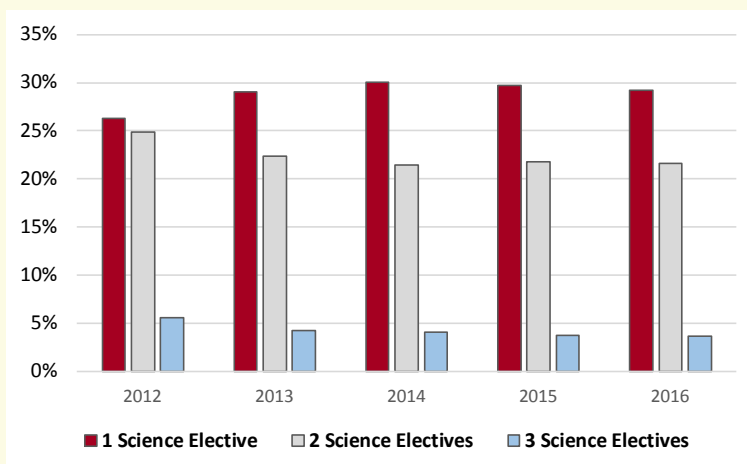
Chart 34: Breakdown of students* who took at least one science Elective



*Percentage share of day school, first attempters sitting science subjects at HKDSE

Source: Hong Kong Examinations and Assessment Authority, 2016

Chart 35: Share of students* who took 1, 2 and 3 Science Electives at HKDSE



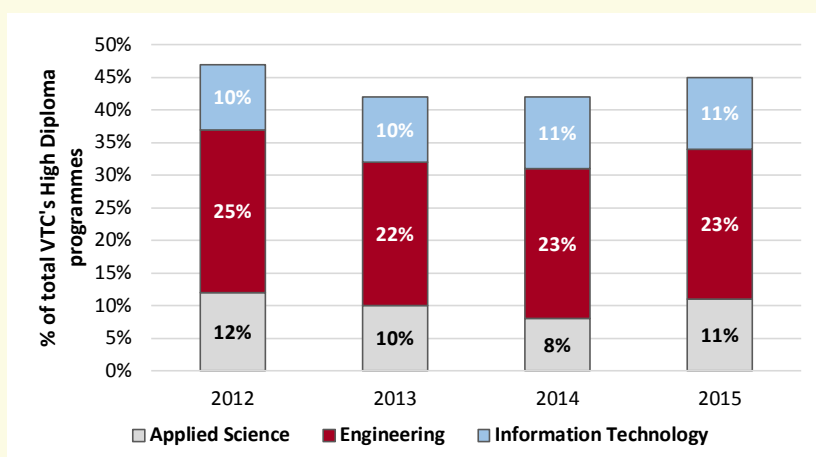
*Percentage share of total day school, first attempters

Source: Hong Kong Examinations and Assessment Authority, 2016

With the abolition of streaming in the HKDSE, students are given broader education opportunities across Humanities and Science subjects, which is supposed to promote balanced personal development. However, the new curriculum comes at the expense of the breadth and depth of both Science and Humanities education, especially for students who took only one Science or Humanities subject. This also creates a problem when school leavers pursue advanced studies in universities, where a broad scientific foundation is required to enable interdisciplinary study. Although remedial or developmental courses are offered by various science or engineering faculties to students with poor foundation knowledge, it is difficult to condense two or more years of studies at the senior secondary school level to one year or less in universities.

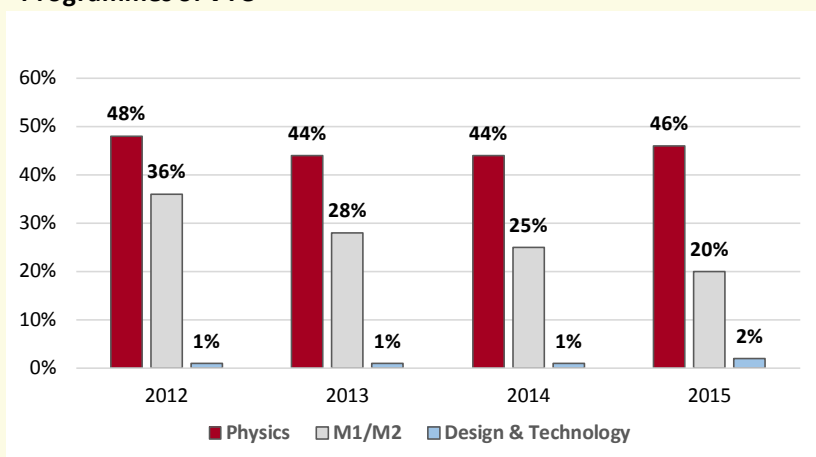
Nor is the problem limited to universities. Certain programmes in post-secondary vocational training, which requires STEM knowledge (Chart 36), is also affected by the narrowing of students' choices of Electives; many HKDSE students end up applying for programmes without possessing any foundation knowledge. In the High Diploma programmes offered by the Hong Kong Institute of Vocational Education (IVE) under Vocational and Training Council (VTC) Group, for example, over half (54%) of students who were admitted into Engineering Study in 2015 did not have any Physics class throughout all or most of their three years in senior secondary schools. Only 20% took advanced Mathematics (M1 or M2), representing a significant drop from the initial cohort of 36% in 2012. Moreover, only 1-2% students had taken the Design and Technology course offered by HKDSE (Chart 37).

Chart 36: Student admission in STEM disciplines in VTC



Source: VTC

Chart 37: STEM background of HKDSE students admitted into Engineering High Diploma Programmes of VTC



Source: VTC

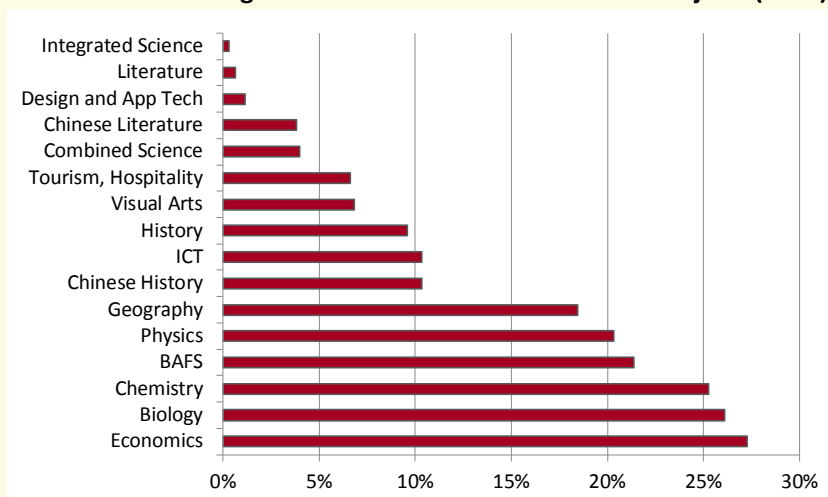
Similarly to universities, the IVE has to respond to its students' deficiency in STEM knowledge by offering remedial courses. However, unlike universities, which have one more year of formal learning under the new system (increased from three to four years), the IVE has to reduce its original programme design from three years to two in order to match the Associate Degree programmes of other post-secondary institutions. This creates even more stress on teachers as well as students and often results in having classes after school hours or even lengthening the time required to complete the programme.

High concentration of subjects

Not only is the number of subjects available to individual students small compared to the old system but the overall subject choices offered to or taken by HKDSE students as a whole are rather limited. Based on the EDB's Survey on Senior Secondary Subject Information: 2014/2015, although there are 20 elective subjects offered, there are only 27 popular subject combinations (each taken by more than 1% of students). Among these combinations, 21 of them involve only seven subjects and they account for almost half (45%) of all students' choices in 2015. These seven subjects are: Biology, Chemistry, BAFS, Economics, Physics, Geography and History.

This high concentration of subjects underlines an overall narrowing of subject breadth among Hong Kong senior secondary students as a whole. Major “losers” include Chinese History; Chinese Literature; English Literature; History; Information, Communication and Technology (ICT); and Design and Applied Technology (DAT) (Chart 38).

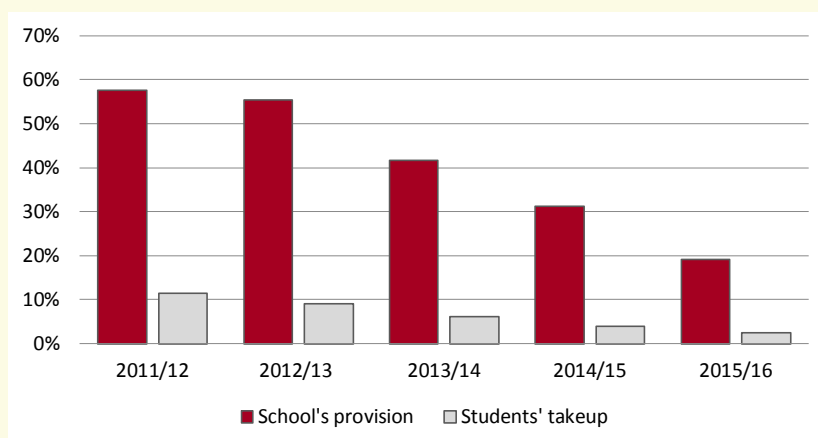
Chart 38: Percentage of HKDSE candidates in selected subjects (2015)



Source: Hong Kong Examinations and Assessment Authority

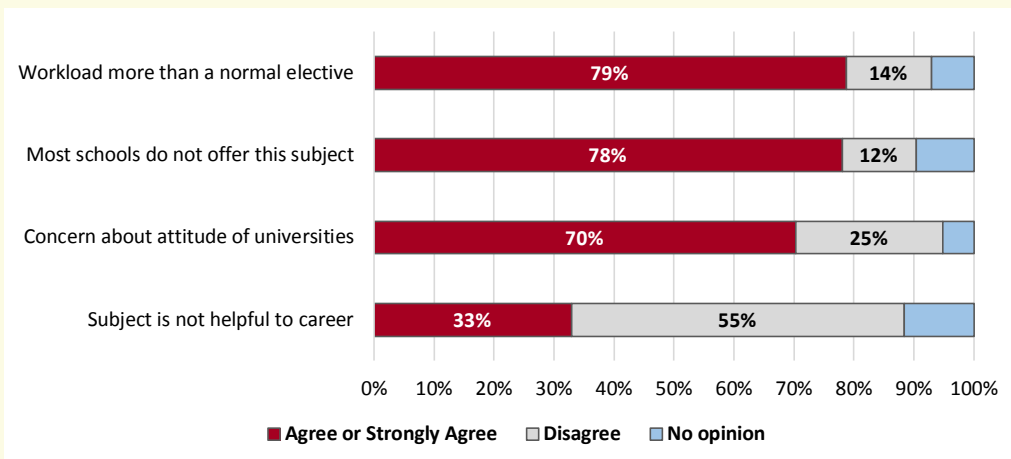
To compensate for the potential drop in the breadth of Science education under the new system, the government introduced an Elective called Combined Science, which is designed to offer a half course on any of the two subjects among Physics, Chemistry and Biology. However, student participation and school provision rates are low and declining (Chart 39). When asked why students are reluctant to take this course, the three reasons most frequently cited are: a) “Students’ workload of this subject is more than a normal full elective” (79% respondents agree or strongly agree); b) “most schools do not offer this subject” (78%) and; c) “Students are concerned about the attitude of universities towards this elective” (70%) (Chart 40). Some stakeholders say that the curriculum positioning of this subject is unclear and should be reviewed.

Chart 39: Schools’ provision and students’ participation of Combined Science



Source: Survey on Senior Secondary Subject Information, Education Bureau, Hong Kong

Chart 40: "Why do you think few students take Combined Science?"

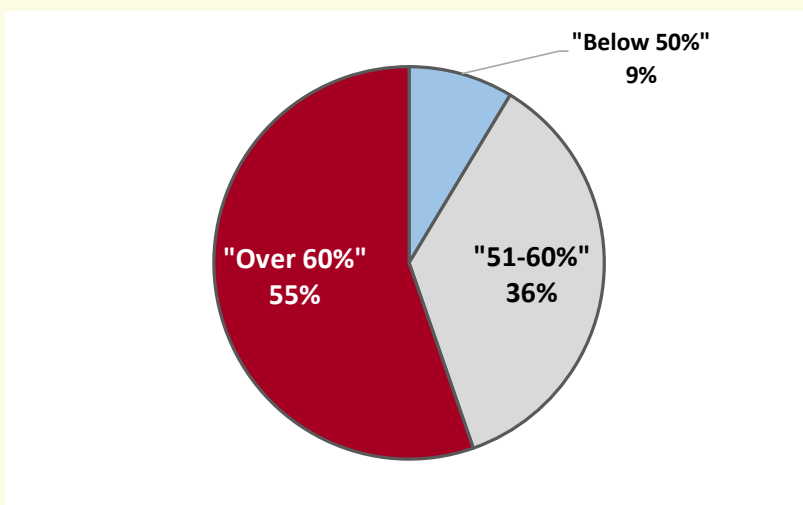


Source: Survey on STEM education, The Academy of Sciences of Hong Kong, (Oct, 2016)

"An oversized Core"?

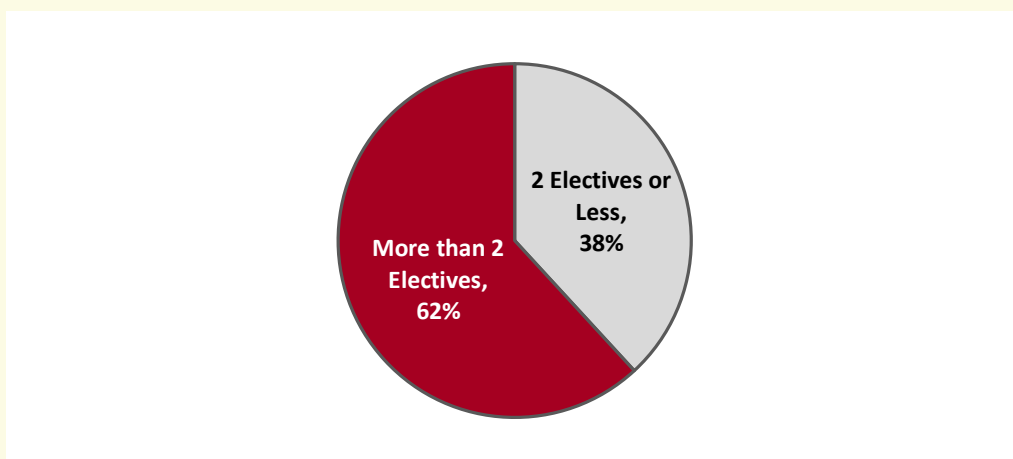
Most school principals we consulted explain the narrowing of students' subject knowledge with the argument that "too much time is taken up by the Core subjects". In our survey, 55% of respondents replied that the four Core subjects have occupied more than 60% of their normal teaching time, while 36% say they took up 51-60% (Chart 41). This is significantly different from the EDB's guidance of 45-55%. Owing to this "oversized Core", there is inadequate time left for Electives. As a result, some schools offer only two Electives for students to choose; according to our survey, only 62% of school principals say they offer more than two Electives whereas 38% offer two or less Electives (Chart 42).

Chart 41: "How much time do you spend on the four Core subjects during school hours (%)"



Source: Survey on STEM education, The Academy of Sciences of Hong Kong, (Oct, 2016)

Chart 42: "Does your school allow students to take any number of electives by their choice?"



Source: Survey on STEM education, Academy of Sciences of Hong Kong, (Oct, 2016)

The tight curriculum structure is well reflected in the extent of teaching required after school-hours, which is a common feature of the new senior secondary education. In the survey, 89% of respondents indicated that they offer after-school-hour classes to students in their schools and that this amounted to an average of 94 hours per year, or around 11% of estimated annualised senior secondary school guided teaching hours.

When asked what the top three subjects offered in classes after school hours were, 69% of respondents named subjects that include the Core Subjects while 62% name just the Electives. More important, of those who allocate more than 60% of their normal teaching time on Core Subjects, 63% say that the Core Subjects are among the top three subjects taught after school hours while 27% replied that the top three are dominated by the Core subjects.

“4C”: the high stake subjects to university admission

Why does the Core take up so much teaching time? As part of the change in the secondary school academic structure, “3-3-2-2” has been set as the minimum JUPAS admission requirement for UGC-funded universities²⁷, along with one or two other Electives. This includes attainment of Level 3 for both Chinese and English Languages and Level 2 for Liberal Studies and Mathematics (as the Core Subjects). However, certain universities have announced that they would look at five subjects in calculating their individual admission scores and, in most cases, without stating clearly subject preferences of individual programmes. Although some universities explain that the introduction of the five-best-subject scoring methodology is to alleviate the pressure of the Core Subjects, since the four Core subjects could also be counted among them, most students and schools reckoned that securing good marks in the four Core Subjects, on top of taking two Electives (4C+2X) was the most “efficient” way to prepare for university admission. (Also see Chapter 4).

²⁷ HUCOM (Head of the eight UGC-funded Universities Committee) was asked to agree to the EDB’s recommendation of “3-3-2-2” (the scores for Chinese, English, Mathematics and Liberal Studies, respectively) be adopted as the minimal university entry requirement; however, it was noted that this minimal requirement would allow roughly 30% of the school leavers to attain this score but that they would be far from the real admission cut-off score for most, if not all, of the university programmes.

Under the prevalent 4C+2X structure, therefore, the four Core Subjects account for two-third of the total unweighted scores. Taking into account the various admission strategies of universities that include “any best 5” or “4C + any best 1/2X”, the Core subjects could account for between 60-80% of the unweighted university entrance scores. The heavy emphasis on the Core Subjects also reduces the impact of strategies such as “2C + any best 3” that encourages students to take three Electives. These considerations make the Core Subjects the “high stakes” subjects of HKDSE and explains why schools and teachers place high priority on them, further exacerbating the examination-oriented, or the teach-to-test (or study-to-test) practice in Hong Kong as mentioned in Chapter 1.

Compared with other systems (Chart 43), the weighting on elective subjects in Hong Kong is low. In the IBDP, Languages and Mathematics account for only 50% of total subjects (excluding Theory of Knowledge) and 50% are on elective subjects. In the 10-state model of US high school graduation requirements (see Chapter 1), Languages, Mathematics and US History account for 38%, or eight credits on average, of the total 21 credits required across the country (see Chapter 1) with over 50% allocated to elective subjects. In the UK’s Advanced Subsidiary and Advanced Level study, most students take three elective subjects, on top of passing the English Language.

Chart 43: Relative weighting of languages/Mathematics/Civic Studies Vs. elective subjects

	Languages, Maths & Civic studies	Elective subjects
HKDSE	67%	33%
US*	38%	62%
IBDP	50%	50%
UK	25%	75%

*Please refer Chart 6 in Chapter 1.

Source: Hong Kong Examinations and Assessment Authority, Education commission of the States, International Bacculaureate, Ministry of Education, United Kingdom

University requirement on electives

Besides the 3-3-2-2 minimum entrance requirement, university admission policies also bear an influence on students’ decision on the number of Electives to take in Hong Kong. Not all of the universities require 4C+2X for general admission. Among the eight UGC-funded universities, only five have a 4C+2X general entrance requirement. The others require only one Elective or, one or two Electives. In addition, although some universities give incentives for students with a third Elective, some do not consider the third Elective at all. Finally, while most universities look at five subjects in their score calculation, some strategies such as “any best 5” or “4C + any best Elective” allow students to enter universities by just focusing on one major Elective (Chart 44).

Chart 44: Admission requirement for engineering faculty or general (for those without engineering)

	General entrance requirement	Score calculation	Third elective
University 1	4C+2X	4C+ best 2X	Tie-breaker
University 2	4C+2X	4C+ best 2X	Bonus
University 3	4C+1/2X	4C+ best 1X	Will not consider
University 4	4C+1X	4C+ best 1X	Tie-breaker
University 5	4C+2X	Any best 5	Considered as one of X under "any best 5"
University 6	4C+1X	4C+ best 1X	Bonus
University 7	4C+2X	2C+any best 3	Considered as one of X under "any best 5"
University 8	4C+2X	2C+best 1st X +any best 2	Considered as one of X under "any best 5"

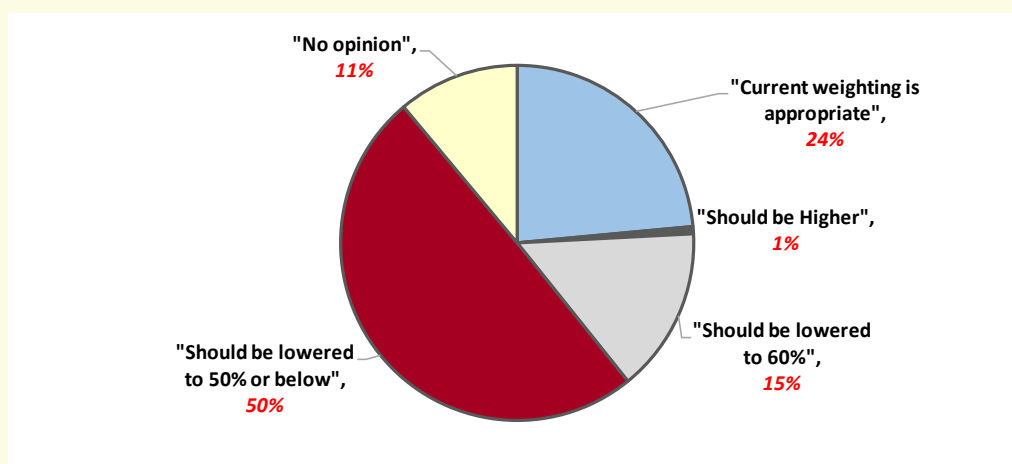
*C stands for Core subject, X stands for Electives

Source: The Chinese University of Hong Kong, City University of Hong Kong, The Education University of Hong Kong, Hong Kong Baptist University, The Hong Kong Polytechnic University, The Hong Kong University of Science and Technology, Lingnan University, The University of Hong Kong

Stakeholders' view on amending the "Core"

There is overwhelming consensus among secondary school principals (88% of respondents agree or strongly agree) that trimming down the Core is needed in order to create space for more Electives. When asked what they think is the appropriate weighting between Core Subjects and Electives, 50% of respondents say 50% or below, while 15% say weighting of the Core Subjects should be reduced from 66% to 60% (Chart 45).

Chart 45: What do you think about the current weighting of Core Subjects vs. Elective (assume 66% students take 2 Electives)?

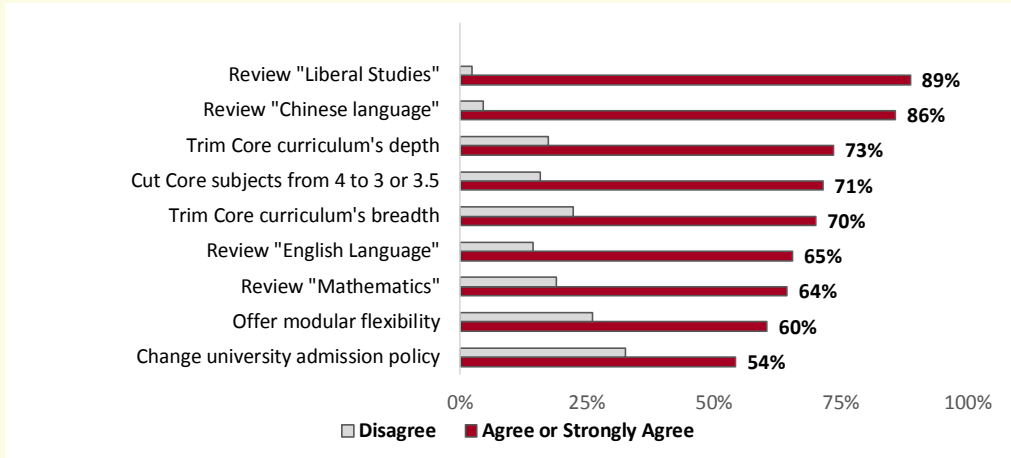


Source: Survey on STEM education, The Academy of Sciences of Hong Kong, (Oct, 2016)

As to how to trim down the Core curriculum (Chart 46), over 50% of those respondents who agree or strongly agree that the Core needs to be trimmed, concur with the following strategies: 1) review the curriculum and assessment of Liberal Studies (89%); 2) review the curriculum and assessment of Chinese language (86%); 3) trim the depth of the Core curriculum (73%); 4) cut Core subjects from four to three or 3.5 (71%); 5) cut the breadth of the Core curriculum (70%); 6) review the curriculum and assessment of English language (65%); 7) review the curriculum and assessment of Mathematics (64%); 8) offer module flexibility with a basic and

advanced syllabus (60%) and; 9) change university minimum entrance requirement from “3-3-2-2” to “3-3” for Chinese and English Languages and individual Faculties and Departments may consider the scores of three other subjects specified in their admission criteria when selecting students to admit (54%).

Chart 46: How to trim the Core Curriculum?



Source: Survey on STEM education, The Academy of Sciences of Hong Kong, (Oct, 2016)

Recommendations:

Scientific innovations and solving complex societal problems are trending towards interdisciplinarity that demands depth as well as breadth of knowledge. Skills and knowledge are equally important to students of the 21st Century and education systems need to strike a delicate balance between the two. In view of the currently “tight” teaching and learning schedule, we recommend trimming down the Core part of the curriculum and injecting flexibility in the entire system to make room for more students to take three elective subjects.

Balancing Core Subjects and Electives. Core Subjects underline the foundational skills that are deemed essential to enable learning to learn by students. This includes language proficiency, numeric fluency, critical thinking and the ability to formulate and express ideas. Notwithstanding their importance, a balance needs to be struck between building skills and the teaching of knowledge to facilitate holistic development and to ensure smooth articulation with further studies or career development. While we do not have strong opinion on the issue, the following are some options favoured by stakeholders for consideration;

- Trim the breadth and depth of the Core Subjects.
- Independently review the new senior secondary school curriculum and the assessment schemes for Liberal Studies, Chinese Language, English Language and Mathematics (in this order).
- Reduce the number of Core Subjects from four to three or 3.5.

Inject flexibility into the system to make room for interdisciplinary STEM study. Students’ learning diversity is cited (Hong Kong Association of the Heads of Secondary Schools, 2009-2010) as the primary challenge facing new senior secondary schools, so tackling that would be a necessary condition to promoting multidisciplinary study. Introducing module flexibility into the curriculum is one way of taking some steam off the curriculum. Moreover, flexibility in the examination system could also go a long way to reducing stress by offering options for students to break down the examination process in tranches to allow them to take the test when they feel ready and by offering them chance to re-sit the examination within a limited timeframe before submitting the results to universities.

Proper recognition of secondary school education. The current HKDSE system is generally perceived to be tailored for university admission, whose policy has an unintended but rather strong impact on secondary school curriculum, pedagogy and assessment. The so-called 3-3-2-2 (for Chinese-English-Math-Liberal Studies scores) JUPAS minimum entrance requirement for the eight UGC-funded universities has resulted in an disproportionately large amount of time on the four core subjects, leaving inadequate time for more elective subjects in secondary school learning. Such narrowing of subject knowledge of our school leavers runs counter to the T-shaped knowledge required for the 21st century and hinders the development of multidisciplinary training needed for innovation and scientific research. We recommend that universities’ admission requirements be decoupled from the standards the government sets for secondary school education.

- **University admission.** Universities should be given autonomy in stipulating their own minimum entry requirements and administering their own

recruitment procedures. Admission criteria should be appropriate to the course. We recommend that universities review the 3-3-2-2 common minimum entrance requirement policy and realign admission criteria to the needs and preferences of individual degree programmes when assessing the candidates' HKDSE results. Focus should be on reducing the Core Subject requirement to make room for candidates to take more Electives. Universities may consider reducing the number of subjects for score calculation from current five or six to say, three only and setting a more flexible minimum admission requirement over the relatively rigid 3-3-2-2 standards currently adopted. Finally, a broader set of criteria other than academic scores such as school records, extra-curricular activities and community services could also be considered.

- ***Certification of Secondary School Graduation.*** To ensure that students attain the necessary skills as well as depth and breadth of knowledge that are deemed essential in the new senior secondary education, we recommend reinstating a secondary school graduation certificate to give due credit to students who have completed senior secondary school training. To cater for student diversity, qualifications should be set to encourage students to study the Core subjects and two or three electives but also allow high flexibility to ensure that students with diverse interests and aptitude have equal chances of success. An option to consider would be the requirement of a total score of 10 for the four Core Subjects (with a minimum of the score of two for each) plus any single best Elective.

Chapter 4: Language at the expense of STEM?

For last year's words belong to last year's language and next year's words await another voice.

T.S. Eliot

Language proficiency is regarded as one of the pillars, among others, of the latest education reform. To be biliterate and trilingual is considered as a “core” skill for a person to thrive in a cosmopolitan city and financial hub like Hong Kong, along with the ability to understand contemporary issues and to command basic Mathematics skills. This is part of the broad-based education reform to foster “whole-person development”.

Concerns, however, are raised that the new secondary system places high emphasis on language skills as compared to the old systems and that it may disadvantage students who are STEM savvy. Under HKDSE, three out of the four “Core” subjects or half of the six subjects (“4C+2X”) currently prevalent among students are either language or language-centric subjects. They include Chinese, English and Liberal Studies. It is of interest to note that, under HKCEE, languages accounted for only two out of seven or eight subjects and, that for HK A-Level, only two language subjects were made mandatory and there was no Liberal Studies.

In addition, university admission under the old A Level system required students to pass only the two language subjects, that is, attain Grade E or above, but their scores were not calculated as part of admission scores, except for certain departments. This was changed after 2012 as scores of the two languages and Liberal Studies, being part of the Core subjects, have been included in most score calculations for university admission. This change is considered part and parcel of the introduction of “3-3-2-2” minimum entrance requirement on the four Core Subjects as discussed in the Chapter 3. Although universities retain high level of independence in their admission requirements, many of their policies such as “4 Core Subjects + 1 best Elective” or “Best-5” are still very much structured within the framework of 3-3-2-2. (See Chapter 3 for more detailed discussion on this topic).

Under the new system, therefore, language proficiency is perceived to have a high impact on university admission. It could have disadvantaged most students who aspire to pursue a Science major at the university level. For instance, the two language subjects plus Liberal Studies could amount to a minimum of 40-60% of the total unweighted scores under the current “5-best subjects” university admission scheme, on both the “4 Core Subjects plus 1 best-Elective” or the “best-5” schemes. As discussed above, the candidates would still have to attain the minimal requirement of Level 3 for the two Languages and Level 2 for Liberal Studies. To arts-oriented students, however, science-related subject amount to only one out of their five subjects, or 0-20% of their unweighted university admission score, provided that they achieve the minimum Level 2 on Mathematics.

Are high-performing STEM students being disadvantaged from entering universities? Our study of HKDSE results and admission to the eight UGC-funded universities failed to find adequate evidence to support the case. In our study with

data from HKEAA²⁸, we first used 15,000 as the total number of students eligible for admission to UGC-funded programmes and determined that the average unweighted university admission scores for students who gained admission under the “best-5 subjects with core subjects at 3-3-2-2 or better” scheme was around 19 and 21 for 2015 and 2016, respectively. We then tried to find out the number of students in the above groups who achieve high scores in STEM-related subjects but fail to pass the Level 3 Language hurdle for either Chinese or English for university admission under two scenarios: (a) attainment of three STEM subjects with Level 5 or above or (b) two STEM subjects with Level 5* or above, assuming the students take six subjects. Based on data from HKEAA, we have found that the number of students in the former group (a) was 113 in 2016 (down from 242 in 2012) and, the number of students in the latter group (b) was 66 in 2016 (down almost half from 2012). As such, past examination results offer little support for the argument that high-performing students in STEM subjects are being disadvantaged under the new HKDSE system (Chart 47).

Chart 47: Students attained below level 3 in either Chinese or English at HKDSE

	Attained level 5 or above in any three STEM subjects	% of first year intakes of UGC-funded programmes	Attained level 5* or above in any two STEM* subjects	% of first year intakes of UGC-funded programmes
2012	242	1.6%	123	0.8%
2013	161	1.0%	77	0.5%
2014	146	0.9%	66	0.4%
2015	146	0.9%	74	0.5%
2016	113	0.7%	66	0.4%

*STEM subjects include Mathematics Compulsory Part, Mathematics Extended Part (Calculus and Statistics), Mathematics Extended Part (Algebra and Calculus), Biology, Chemistry, Physics, Integrated Science, Combined Science, Information and Communication Technology

Source: Hong Kong Examination and Assessment Authority, The University Grants Committee

Nor has there been any material change in university’s minimum standard requirement on languages, other than the addition of the Liberal Studies. Based on a research study conducted by HKEAA to compare the International English Language Testing System (IELTS) scores of HKDSE English Language in 2012 to that of HKCEE and HKALE in 2004, the mean IELTS band score of HKDSE’s Level 3 of 5.58 is slightly below that of HKALE Use of English’s Grade E (5.88) but higher than HKCEE English Language (Syllabus B)’s Grade E (5.06) (Chart 48).

Chart 48: Mean International English Language Testing System (IELTS) band score

HKDSE	IELTS (2012)	HKALE	IELTS (2004)	HKCEE	IELTS (2004)
5**	7.64	A	7.56	A	7.03
5*	7.24	B	7.16	B	6.65
5	6.9	C	6.83	C	6.22
4	6.41	D	6.28	D	5.82
3	5.58	E	5.88	E	5.06
2	4.93				

Source: Hong Kong Examinations and Assessment Authority

²⁸ From Hong Kong Examination and Assessment Authority (HKEAA): “Grade point distribution in the best five subjects”, HKDSE results Released, 2015 & 2016

The only notable difference, however, is that under the A Level, the passing rates of English and Chinese are much higher, at 75% and 95% (2010), whereas under the HKDSE, they are around 55%. This drop is likely the result of our shift from an elite to a broad-based education. On an absolute basis, the pool of qualified students is actually higher under the HKDSE than the HKAL, especially after adjusting for the drop in the age cohort group (Chart 49).

Chart 49: Pass rate of Chinese and English for university admission

	Pass Rate		Number of Students		Population Age 15-24
	English	Chinese	English	Chinese	
HKAL - 2010 [^]	75%	95%	22,341	28,360	878,025
HKDSE - 2016 [*]	55%	55%	30,138	29,834	761,300

* Day school first attempters getting level 3 or above

[^] Day school first attempters getting E Grade or above

Source: Hong Kong Examinations and Assessment Authority

However, there are drawbacks in the above methodology. First, examination results may not be a good measurement of the impact of languages on STEM-oriented students. Second, students are quick to adapt to new systems and rules, as reflected in the declining number and percentage share of the aforementioned high-achieving STEM students. In order to gain admission to universities, students will try their best effort to attain the 3-3-2-2 minimum requirement. As such, STEM-oriented students may have spent a disproportionately large amount of time and effort on languages, as compared to their counterparts who are strong in languages. This latter hypothesis is nonetheless yet to be supported, and careful analyses of well-designed surveys on students would be required to gain better insight on this topic.

Finally, as part of the language issue, some stakeholders have also raised concerns over the design of the Chinese curriculum and its assessment. Since this issue is beyond the scope of the present study, further research by relevant authorities is warranted.

Recommendation:

Language and STEM are both important skills and knowledge that students need to come to grasp with in order to thrive in a knowledge-based economy. STEM enthusiasts need to be able to formulate the question, to argue, explain and debate their scientific findings in a cogent and lucid manner in order to excel. As such, Language and STEM are not mutually exclusive and can reinforce one another. The art, however, lies in striking a balance between them.

- ***Consider school recommendation in university admission.*** Talent is difficult to measure and talented students are definitely non-uniform; some of them could be more talented in language/humanities and some more skilful in their quantitative techniques and more interested in natural science. Universities should take into consideration the wide range of student aptitudes in their admission process. For example, universities should consider granting entrance exemption for students who are gifted in certain areas but fail to meet the minimum language requirements, especially if the students have strong recommendations from their schools.

Chapter 5: Others: Information and Communication Technology (ICT)

As one of the key players and drivers behind the recent spate of technology innovations and job growth, Information and Communication Technology (ICT) (or Computer Studies in other countries) has been in the forefront of STEM curriculum reform in the last few years. It has come a long way. From being a niche area for the advanced cohorts in the 1970s and 80s, Computer Science has morphed into ICT to promote computer and digital literacy as personal computers and internet took off in the 1990s and '00s. With the advent of new Internet-related technologies and applications, focus is now shifting to treat Computer Science as a discrete, rigorous discipline at senior secondary education. In addition, latest thinking places computational thinking and programming as one of the key competence areas needed for the 21st Century with countries starting to integrate coding into their primary and secondary education curriculum, either compulsory or optional (Chart 50). All these mirror a change in social attitude towards coding and computing globally and in Asia as start-ups, non-governmental agencies and businesses sprang up to offer out-of-school coding classes and teaching material for children and teenagers.

Chart 50: Integration of Computing into primary and secondary education

	Primary	Lower secondary (general)	Upper secondary (general)
Denmark		○	○
Estonia	○	○	○
UK	●	●	
Belgium	●	●	
Finland	●	●	
France		●	
Luxemborg			
Netherlands	○	○	○
USA			○
Korea ¹	●	●	●
Singapore ²		○	○
Hong Kong ³		●	○
Israel			○

● Compulsory; ○ Optional

¹ Korea government plans to make Computing compulsory for elementary schools in 2017 and for high schools in 2018, the Granite Tower, Nov, 2014

² Some secondary schools in Singapore to start offering programming as an O-Level course, beginning 2017

³ Beginning 2016/17, 30% of curriculum time under Information and Communication Technology (ICT) will be devoted to the study of programming

Source: European Schoolnet, Oct, 2014 (for European countries), Education Bureau, Hong Kong,

Computing curriculum in Hong Kong

In Hong Kong, the government recently announced that coding would be made compulsory for junior secondary students, starting 2016/17, mandating 30% of the curriculum time of Information and Communication Technology (ICT) to be devoted to programming²⁹. At the senior secondary education level, however, the curriculum looks outmoded as it still fuses IT literacy and practical IT applications with Computing as a Science (Chart 51). Programming is but one of the four elective modules under ICT, rather than being the foundation of the curriculum. In the Compulsory Part, which is supposed to contain the key concepts of the subject discipline, “Basic Programming Concept” accounts for only 14% of the guided teaching hours. Altogether, including school-based assessment, programming constitutes no more than 50% of the entire curriculum. This does not dovetail with global trends that are shifting towards programming and computational thinking as the fundamental core of Computing Science.

Chart 51: Senior secondary school curriculum on Information, Communication and Technology

Curriculum on Information, Communication and Technology	No. of hours
Compulsory	145
A. Information processing	54
B. Computer system fundamentals	25
C. Internet & its Applications	24
D. Basic programming concept	20
E. Social implications	22
Electives	75
A. Databases	
B. Data communication & networking	
C. Multimedia production and web site development	
D. Software development	
School base assessment	30

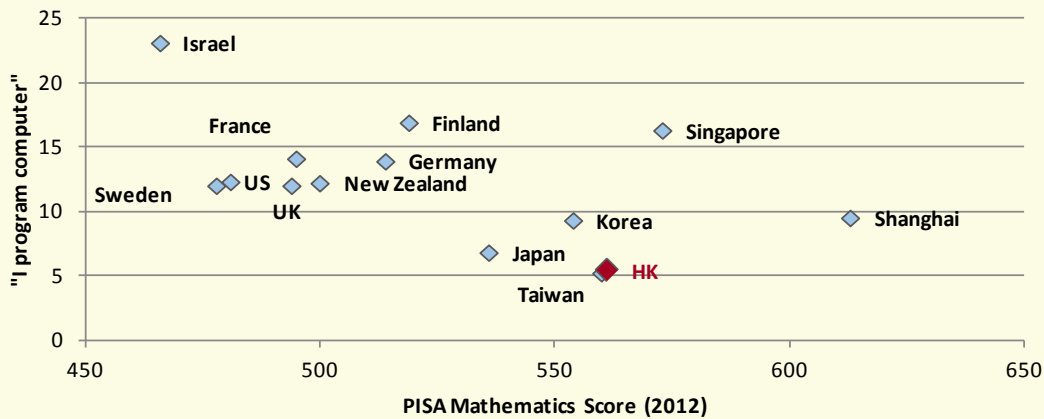
Source: Education Bureau, Hong Kong

Hong Kong (and Asia) is lagging behind in student exposure to coding

The biggest challenge confronting student enrolment of ICT and programming however, lies in student and social attitudes towards the subject. Compared to other developed countries, Hong Kong, along with many regional peers, lags behind in student exposure and experience with coding, according to a PISA survey in 2012 on 15-year-old students (Chart 52). When asked if they have programmed a computer, only 5% of Hong Kong’s students responded affirmatively. This is compared to 12-17% of respondents from the US and some European countries and 23% in Israel. It is interesting to note that in Asia, despite the highly-ranked achievement in Mathematics, most regional peers, with the exception of Singapore, have similarly low student exposure to programming.

²⁹ Education Bureau, The Government of the Hong Kong Special Administrative Region, (Dec, 2016) “Report on Promotion of STEM Education – Unleashing Potential in Innovation”.

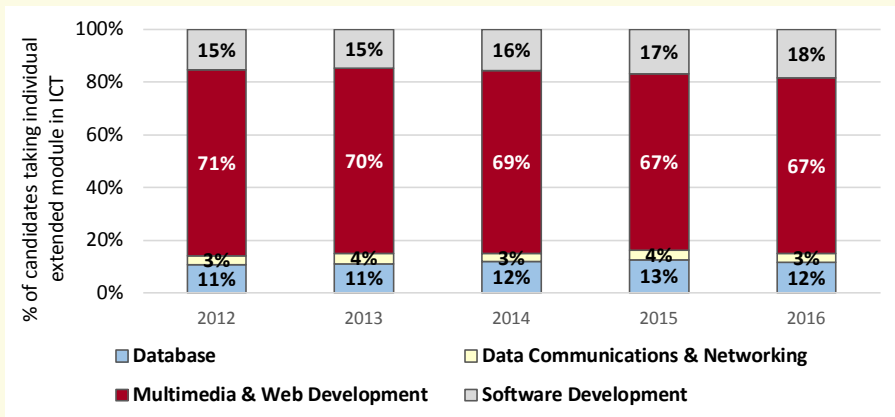
Chart 52: Students' experience with programming and Mathematics attainment



Source: OECD, PISA 2012 Database

In Hong Kong, the demand for ICT study at senior secondary schools (11%) is much lower than school provision rate (around 90%) and lower than the enrolment rate of Business, Economics or other Science subjects (Chart 38 in Chapter 3). More importantly, enrolment to programming under ICT is meagre. In 2016, for instance, out of 6,407 HKDSE candidates who registered for ICT, only 1,171 or 18% selected Software Development as their Elective module, while the majority (67%) chose Multimedia Production and Web Site Development (Chart 53).

Chart 53: What Electives do students take within ICT?



Source: Hong Kong Examinations and Assessment Authority

Social attitudes towards career prospects of Information Technology (IT) and Computer Science in general are widely seen to be improving, after the downturn in the aftermath of the TMT (technology, media and telecommunications) bubble in the early part of the century. While these enrolment data do not yet reflect the latest student attitude towards the subject, it is important to monitor if enrolment at senior secondary school matches the rebound as seen in the Computer Science departments at local universities. To help students in their subject decisions, transparency and effective delivery of the latest market information relating to skillset requirement of the labour market as well as job prospects are of paramount importance.

Recommendations:

As computers and the Internet have transformed our lives, digital literacy is essential to live and work in today's world. In addition, ubiquitous digitisation opens up boundless opportunities for innovation and career development that can be captured by a solid education in Computing. We argue that digital literacy and Computer Science should be separated, with the former made compulsory for all students while the latter be revamped into a rigorous curriculum that focuses on programming and computational thinking. Moreover, investments should be made in school counselling to ensure that students and parents receive up-to-date information on potential careers that the study of Computer Science affords.

- **Digital literacy** should be taught to all primary and secondary schools students. This includes the basic use of computer and digital devices, plus the Internet as well as its usage in the modern world context encompassing issues such as privacy, cyber-ethics and security. A basic understanding of how programming works and the logic, data structure and algorithms behind the working of digital devices should also be introduced at primary and junior secondary level.
- **Computing as a Science.** A solid foundation built on programming and key concepts of computational thinking at senior secondary education is highly beneficial for students who aim to pursue a career that touches on digital technologies or advanced study in computing or other disciplines that involve modelling. We recommend revising and streamlining the current ICT curriculum to place more emphasis on coding. Programming and key concepts of computational thinking should form the core part of the Compulsory section.
- **Teachers' training on coding.** Rigorous continuous professional development (CPD) on coding should be made available for teachers to update them on languages and latest development trend. Training programmes should involve universities, non-profits and industries and should promote collaborative sharing and networking among stakeholders.
- **e-Learning,** which provides a real life experience for students to practice and use digital technology to enrich their learning experience, should be implemented at all schools at the earliest. This entails making Wi-Fi available at schools, efforts to ensure that all students are provided with digital learning devices as well as the provision of e-learning materials and other resources. To complement the completion of Wi-Fi at schools in end-2017, the government needs to coordinate efforts to build the e-learning infrastructure involving different stakeholders.

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The Academy promotes and advances the teaching of science and technology, educates and informs the public on relevant issues, cooperates with the industrial and commerce sectors to strengthen the application of research results, and conducts independent studies on issues relating to public policy on science and technology research and education.

The Academy was inaugurated on 5 December 2015 at the Government House, witnessed by the Chief Executive, The Hon C Y Leung, Minister of Science and Technology, Professor Wan Gang, President of the Chinese Academy of Sciences, Professor Bai Chunli, and representatives from fellow academies, foreign consuls and community leaders of various sectors in Hong Kong.

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