大學教育資助委員會
University Grants Committee

研究評審工作
Research Assessment Exercise 2020 HONG KONG
大學教育資助委員會 UNIVERSITY GRANTS COMMITTEE

RESEARCH IMPACT IN HONG KONG UNIVERSITIES: **Evidence from the Research Assessment Exercise 2020**

A summary report by
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Commissioned by the University Grants Committee
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01 Aims of the RAE

Every six years or so the UGC conducts a Research Assessment Exercise (RAE). This is part of its commitment to assessing the performance of UGC-funded universities, and is intended to encourage world-class research and drive excellence.

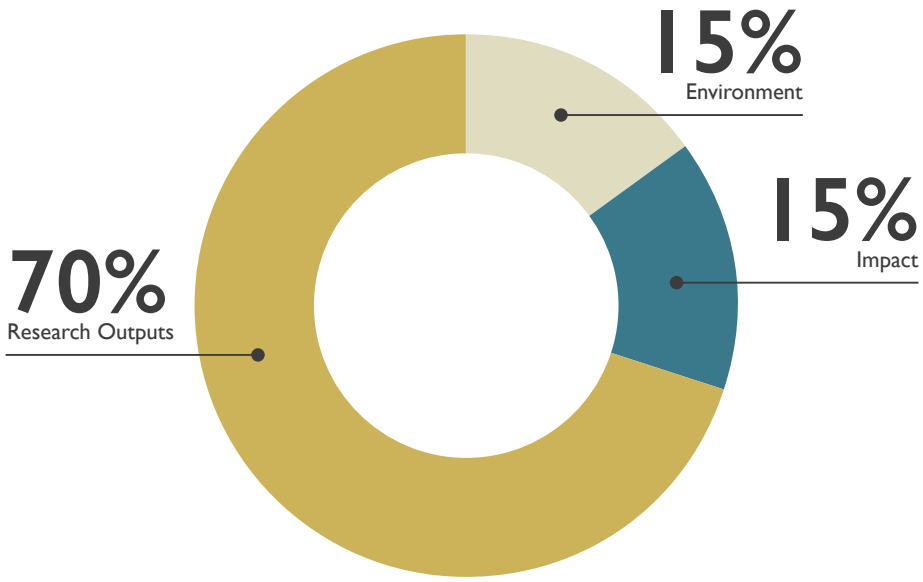
UGC policy for research in the universities that it funds has two objectives:

a) to participate in the global endeavour to extend human understanding thus keeping the knowledge base in the universities current; and

b) to encourage research tied to the interests and needs of the community.

With a view to incentivising the conduct of research of social relevance with high economic and social benefits, while recognising the impact brought about by the universities' research, the UGC decided in 2016 that the next RAE in 2020 would include some changes from its 2014 predecessor.

As well as assessing the quality of 'Research Outputs' – such as research publications and other forms of presenting original research - and the surrounding 'Research Environment' – the strategy, resources and infrastructure that support research and underpin its vitality and sustainability - the RAE 2020 would also include a component that was new to Hong Kong. This was called 'Research Impact'.



Research Impact, put simply, is the use of knowledge obtained through research to affect the world beyond academia, e.g. in industry, health, the environment or society more generally.

In the RAE 2020, Impact was formally defined as the **demonstrable contributions, beneficial effects, valuable changes or advantages** that research qualitatively brings to the economy, society, culture, public policy or services, health, the environment or quality of life locally, regionally or internationally; and that are **beyond academia**. Impacts could be positive or constructive effects on any of the above, or reductions or prevention of harm, risk, cost, or other negative effects.

The Impact element would particularly contribute to the UGC's objective of providing accountability for public investment in research and producing evidence of the benefits of research.

While novel in Hong Kong, with questions being raised about, e.g., how feasible it was to assess impact, or what value this part of the exercise would have, prior experience in the UK (where similar concerns had been aired) showed not only that it was possible to make a reasonable assessment of impact, based on verifiable evidence, but also that the impact element 'contributed to an evolving culture of wider engagement, thereby enhancing delivery of the benefits arising from research, as captured through the impact case studies'. [*Building on Success and Learning from Experience: An Independent Review of the Research Excellence Framework* (Stern Review, 2016), para. 15]. Stern also observed that 'The introduction of impact into REF2014 yielded valuable insights into institutions' wider social and economic activities and achievements…. it can help foster institutional strategy to encourage greater societal engagement by researchers and act as a platform for marketing and internal learning'. [Para. 18].

The weighting of 15% would give this new element significance, with the overall assessment nevertheless still being dominated by the review of the quality of research outputs.

02 Process

The assessment was conducted by panels of experts across all the fields of research represented in Hong Kong universities. Thirteen panels, covering 41 research fields – called 'units of assessment' – were set up. Because the aim is to benchmark Hong Kong research against the best international standards, most of the panel members (about 70%) were leading experts from around the world, with the remainder from Hong Kong universities.

Additional local 'research end-users' were appointed to each panel. These were professionally qualified people from business, government, industry and the arts of the relevant fields. Their role was to apply experience from outside academia to help inform the overall assessment of the plausibility of claimed impacts and supporting evidence.

What evidence did these panels receive from the universities?

Universities submitted evidence of the impact of their research on a unit of assessment basis. These had to cover impacts that the university had enabled between 1 October 2013 and 30 September 2019, underpinned by research supported by the university between 1 January 2000 and 30 September 2019. The longer time period for the underpinning research reflected the lead times that often fall between initial research and a clear impact. The universities had to demonstrate the impact they have enabled during the six years of assessment based on the underpinning research over the last 20 years.

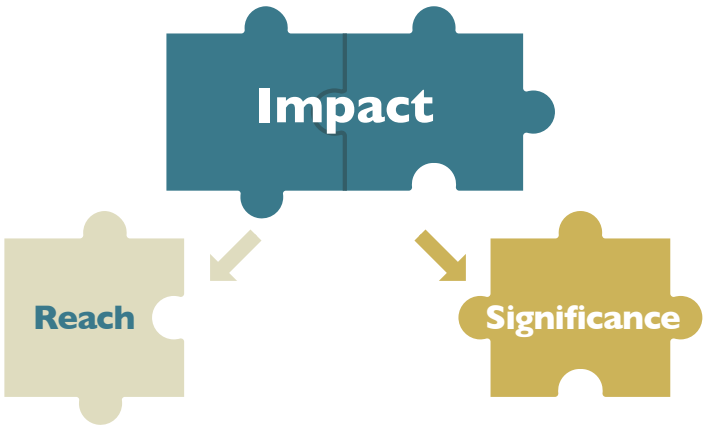
Each submission included:

a) an *impact overview statement*, laying out the submitting unit's approach to enabling impact from its research. This might give contextual information about the wider range of activities within the submitting unit, its relation to the university's overall impact strategy, and the unit's strategy and plans for supporting impact;
b) one or more (depending on size of the unit of assessment) *case studies* describing specific examples of impacts achieved.

The case studies were intended to *illustrate* the impact achieved by the submitting unit, *not* to give a comprehensive account of where all their research had led. They had to include:

i) information on the underpinning research;
ii) a detailed narrative explaining the "pathway to impact", i.e. how the research led to the impact, what the unit did to enable this process, the beneficiaries and nature of the impact, and evidence illustrating the extent of the claimed impact;
iii) sources external to the submitting university that could corroborate the claims made (e.g. appropriate people in industry, public sector bodies, charities … depending on the nature of each case).

On the basis of this information, panels assessed Impact in terms of two criteria, called 'Reach' and 'Significance' – assessing the two criteria together in a **holistic manner**.



a) **'Reach'** is the extent and/or breadth of beneficiaries of the impact;
b) **'Significance'** is the degree to which the impact enabled, enriched, influenced, informed or changed the products, services, performance, practices, policies or understanding of commerce, industry or other organisations, governments, communities or individuals.

The application of these criteria can be illustrated by an analogy. Imagine a cylinder which is narrow ('reach') but tall ('significance') and another that is wide but shallow. Despite the difference in shape, their volume ('impact') may be the same, implying similar overall impact. Different volumes, though, might be taken to imply different levels of overall impact.

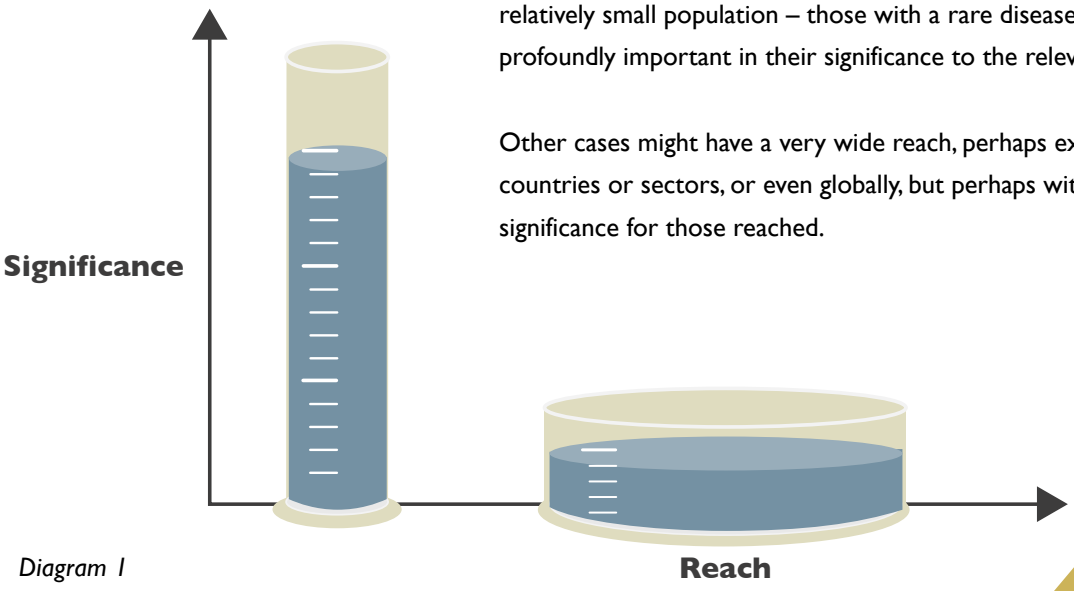


Diagram 1

So, some cases might be relatively limited in reach (perhaps impacting on a relatively small population – those with a rare disease, for example), but profoundly important in their significance to the relevant population.

Other cases might have a very wide reach, perhaps extending across large countries or sectors, or even globally, but perhaps with more limited significance for those reached.

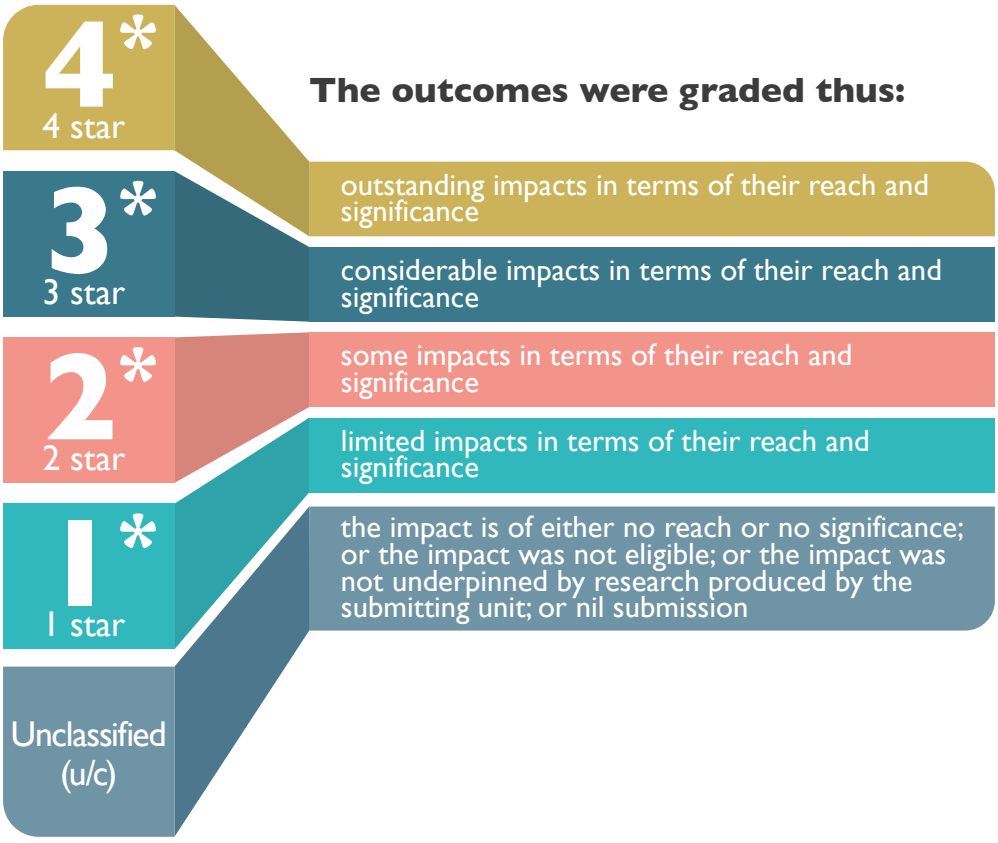
Some, finally, might have both extensive reach *and* significance – and might expect to be graded accordingly.

The panels took a view of reach and significance considered as a whole – that is, not assessed separately. This approach was designed to reflect the huge potential variability in the nature of impacts.

It is important also to note that the geographical location of the impact did not matter. It might, for example, be confined to Hong Kong, or even a specific community or sector within Hong Kong, or similarly within another region/country. Or it might be widely international in scope. Panels were to judge 'reach' in terms of what was an appropriate ambition for the impact in question. In other words, how far had the impact claimed achieved the maximum reach within its potential domain of applicability (e.g. population, geographical boundary, audience, etc.)

A convincing narrative was required, showing how some research undertaken within the submitting unit of assessment had underpinned a worthwhile impact in the wider world. Activity alone (such as giving talks, or securing patents) did not count as impact. Rather, something had to be shown to have changed in the wider world.

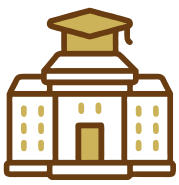
In other words, case studies had to show a clear pathway between the initial research and the eventual outcome, and how the submitting unit had contributed to that outcome, together with verifiable supporting evidence.

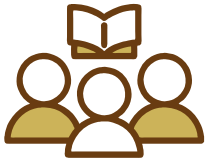


It is these case studies that form the basis of the rest of this document.

03 The Submissions

A total of 345 impact case studies were submitted, distributed across the panels and universities as follows:




8 UGC-funded universities

13 RAE Assessment Panels

41 Units of Assessment

345 Impact Case Studies

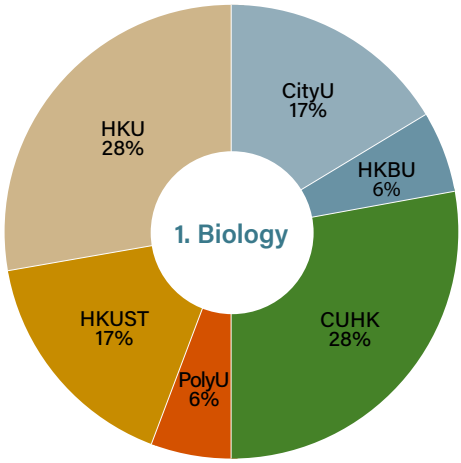
9 Main Impact Areas

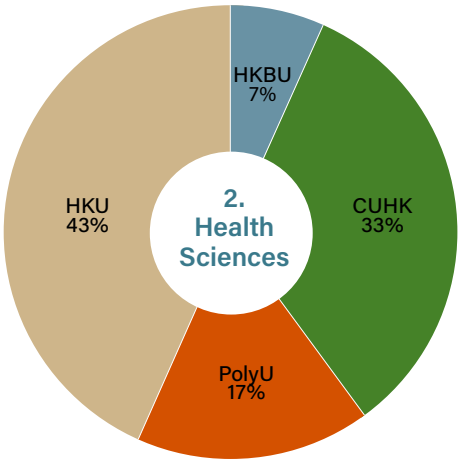
Table 1: Distribution of Impact Cases

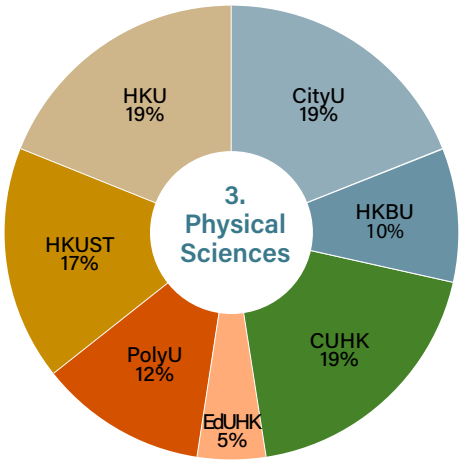
	University								
Panel	CityU	HKBU	LU	CUHK	EdUHK	PolyU	HKUST	HKU	**Total**
1 - Biology	3	1		5		1	3	5	**18**
2 - Health Sciences		2		10		5		13	**30**
3 - Physical Sciences	8	4		8	2	5	7	8	**42**
4 - Electrical & Electronic Engineering	3			3		3	3	2	**14**
5 - Computer Science/Information Technology	3	1		3	1	2	3	2	**15**
6 - Engineering	5			2		5	4	3	**19**
7 - Built Environment	4			1		6	2	6	**19**
8 - Law	2			2				4	**8**
9 - Business & Economics	9	6	5	8		12	8	7	**55**
10 - Social Sciences	7	6	4	9	6	3	2	9	**46**
11 - Humanities	4	6	6	10	5	5	3	9	**48**
12 - Creative Arts, Performing Arts & Design	2	3	1	2	2	3		2	**15**
13 - Education	1	2		4	5			4	**16**
Total	**51**	**31**	**16**	**67**	**21**	**50**	**35**	**74**	**345**

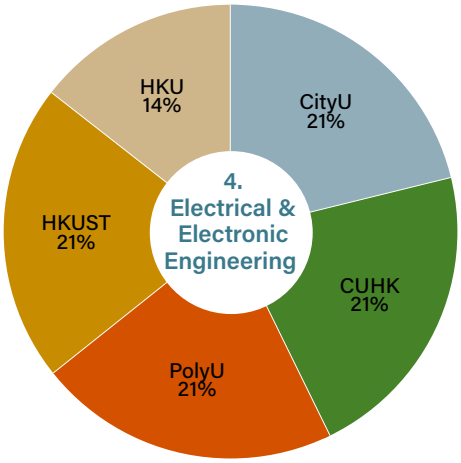
This table shows the relative scale of each university's submissions (itself, of course, related to university size), and submissions per panel, which reflects the disciplinary makeup of the UGC funded universities.

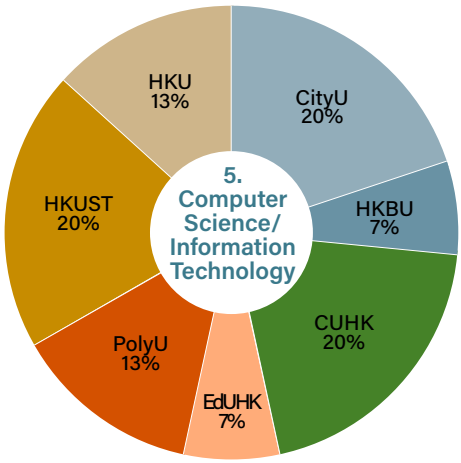
Distribution of University's Impact Submissions Across Panel 1-6

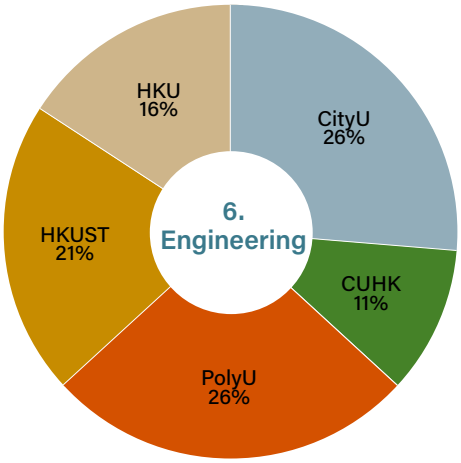




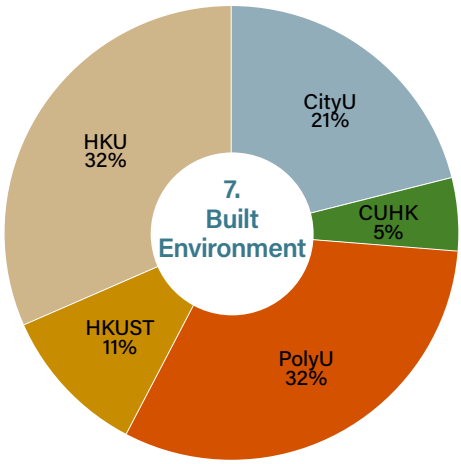


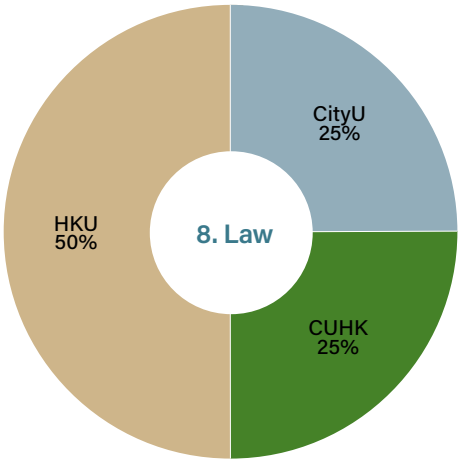


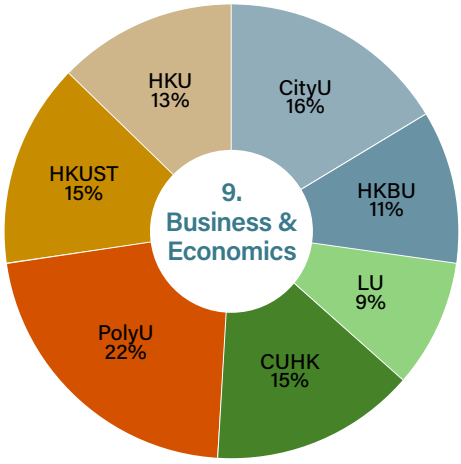


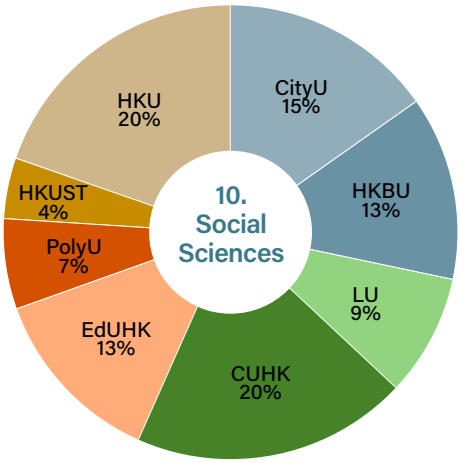


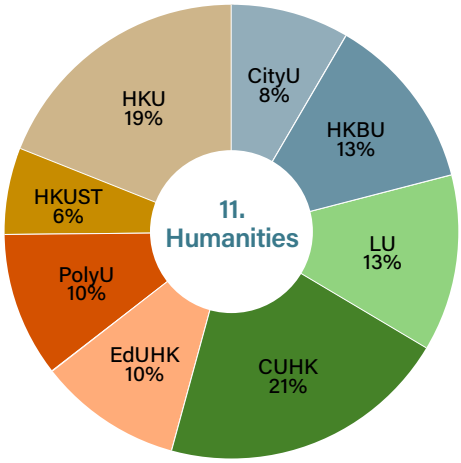
Distribution of University's Impact Submissions Across Panel 7-13

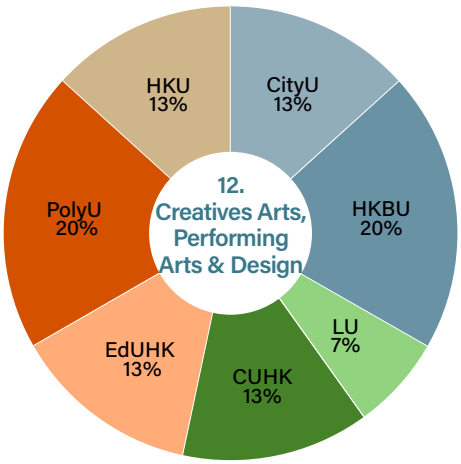


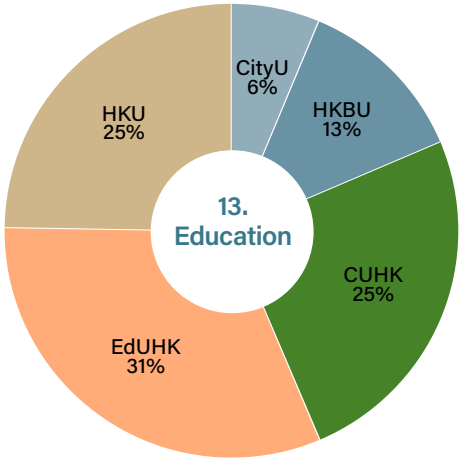












04 What They Showed

The submissions (published at UGC's website: https://www.ugc.edu.hk/eng/ugc/activity/research/rae/2020/impactsubmissions.html), show how **far-reaching and active** is the engagement of all the UGC funded universities with the society and economy of Hong Kong and beyond.

The ratings awarded show the overwhelmingly **very high quality** of impact that the cases demonstrate. In total, 80% were rated Outstanding or of Considerable Quality. Work of 4* and 3* standing was found at every university. The cases assessed at 4*, in particular, have been judged to attain the very **highest standards globally**, and **every university** has demonstrated the ability to perform to this standard.

As mentioned above, the **location of the impact** could be within Hong Kong, beyond Hong Kong, or both. At least 306 (89%) claimed impact **within Hong Kong**, while at least 261 (76%) claimed impact **beyond Hong Kong**. The latter cases overwhelmingly involved impact within Mainland China with many extending (as well, or instead) across Asia more broadly, and/or globally.

It's perhaps also worth noting how the submitted case studies give a very firm sense of a university sector that is strongly integrated with activities in Mainland China, in terms both of research subjects and location of impact. As always, of course, there remains the question of how representative the submitted cases are of all activity.

The case studies collectively give a striking impression of the sheer **energy and commitment that goes into outreach** into schools, the community and society in general, especially some of the less advantaged groups.

This activity is too numerous, and is reported in too many different ways, to be easily captured quantitatively, and has often simply been briefly mentioned at the end of the more formal claims made in the case study. But to give a sense:

A) ***Impact case 1*** – a new technique for photo-catalytic fabrication of thin films, which led to sales to 3500 overseas clients, also resulted in extensive media outreach, and an exhibition at HK Science Museum in 2004 and InnoCarnival in 2018;

B) ***Impact case 2*** – a new approach to assessing marine pollution underpinned work to conserve horseshoe crabs, and also led to an outreach programme that provided crabs to over 2700 school students, with guidance over rearing for 6 months, before participating in annual group wild releases;

C) ***Impact case 3*** – design and construction of a camera pointing system for the 2013 and 2019 Chinese lunar landers, capturing images from the near and *far sides* of the Moon, with billions of viewers globally, much media coverage in HK and beyond, numerous talks, and an event at the HK Science Museum; leading also to a start-up company in HK using technologies from the lunar cameras work to develop surgical robots, employing over 140 people.

D) ***Impact case 4*** – research into quality control of Traditional Chinese Medicines (TCM) which enabled improved government regulation and safety testing of these products, and assisted their internationalisation, led to the provision of internationally available online databases on TCM which have had over 5 million visitors; a popular series of books in various languages; a television series for international audiences; resources for teaching and research purposes; and facilitating the establishment of a dedicated museum with 150,000 visitors per week.

E) ***Impact case 5*** – research into Hong Kong local histories has led to a series of outputs about prominent historical figures and events. From this work has come teaching kits used by dozens of primary and secondary schools in Hong Kong, and freely available to the public, with over 1000 downloads since July 2018; a mobile exhibition which has been seen by over 1000 students; seminars and workshops for teachers and school students; the first ever gazetteer systematically recording the natural and social features of a Hong Kong village, which acts as a model of its kind and is available in all public libraries; and a range of other activities to encourage popular engagement with local history.

For a more systematic view of the pattern of impacts claimed, the following diagrams offer a schematic analysis of distribution of some of the main impact areas claimed, as submitted to each panel. The categories of impact area shown are, it must be noted, somewhat arbitrarily selected – chosen to cover a number of the most frequently cited impact areas. They are not comprehensive, but are intended simply to give a sense of the scope of the impacts claimed. Nor are they mutually exclusive – that is, there are overlaps between the categories. In addition, individual case studies may well (entirely properly) claim impacts in several areas, and this also is reflected in the diagrams.

It's also important to note that what the RAE required from universities was cases that were simply *illustrative* of the best work of each unit of assessment. The pattern of impact areas displayed in the submitted cases is, therefore, **not necessarily representative** of the full range of each UoA's activity.

Despite these caveats, the following diagrams present a general sense of the areas in which impact has been claimed, and the range of areas which the work falling to each panel impacts upon.

NOTE: The diagrams need to be studied with care, having due regard that the analysis is based on very small numbers and the arbitrariness of the impact areas selected. In addition, the cases are selections from the totality of activity in the universities, so it may not represent the overall balance of activity in each UoA area.

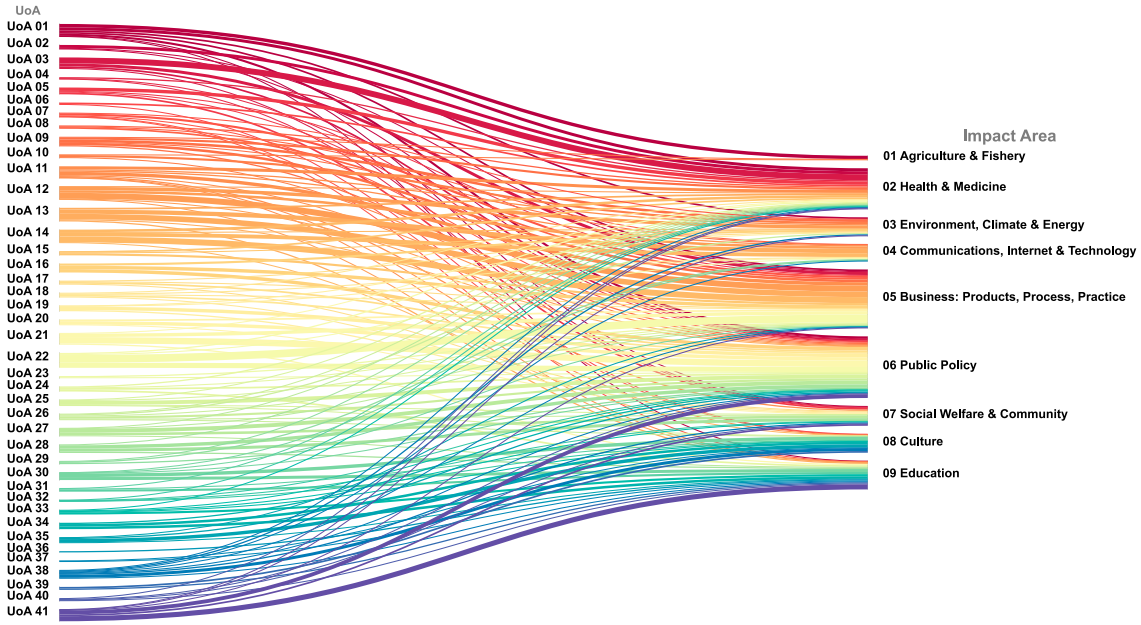


Diagram 2: Alluvial diagram linking UoA areas to impact areas

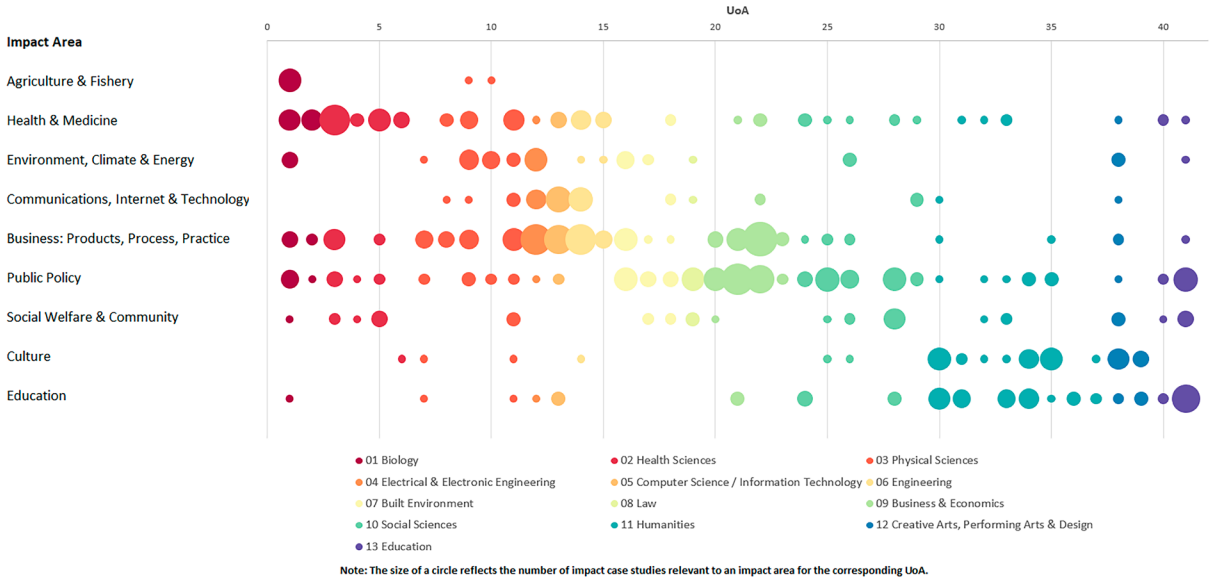


Diagram 3: "Hot spots" illustrating distribution of impact areas by UoA

05 What Were the Main Areas of Impact?

The two largest impact areas, in the categories used here, were **Public Policy** (covering governmental and related bodies at all levels and in any region/place), and **Business** (covering new products, processes and practices), involving cases submitted to almost every panel.

Next were **Health Services** and the practice of **Medicine**, and **Education** (all levels and modes), again covering the spectrum of panels but in slightly lower numbers.

A cluster of activities around **Social Welfare** and **Community** support and development followed, together with another cluster around the **Environment, Climate change and Energy** supply and use (including Green policies).

Another cluster followed around **Communications** technologies, including all sorts of developments involving use of the WWW, and developments in the whole range of **'Tech' industries**. At around the same frequency of observation was a wide array of developments involving the **Cultural sector** (museums and galleries, preservation and promotion of ancient or rare texts and literatures, music, global art exhibitions, design, etc). Attendees, or participants (e.g. online) at some of these events reached prodigious numbers, often in the hundreds of thousands.

Finally (but bearing in mind again the somewhat arbitrary nature of the categories used) was a smaller number of cases bearing on **Agriculture** and **Fisheries**. Some of these, too, presented impacts reaching vast numbers (millions) of people.

06 What Range of Areas Did Individual Panels Address?

All panels displayed one or a few distinct areas of focus, as might be expected from the nature of the activities in each field, coupled with evidence of less concentrated engagement with a much wider range of impact areas. Again, we must recall that we are reviewing here the product of the illustrative cases submitted, and not necessarily a representative cross-section of the current portfolios of the submitting universities.

NOTE: The following diagrams need to be studied with care, having due regard that the analysis is based on very small numbers and the arbitrariness of the impact areas selected. In addition, the cases are selections from the totality of activity in the universities, so it may not represent the overall balance of activity in each panel area.

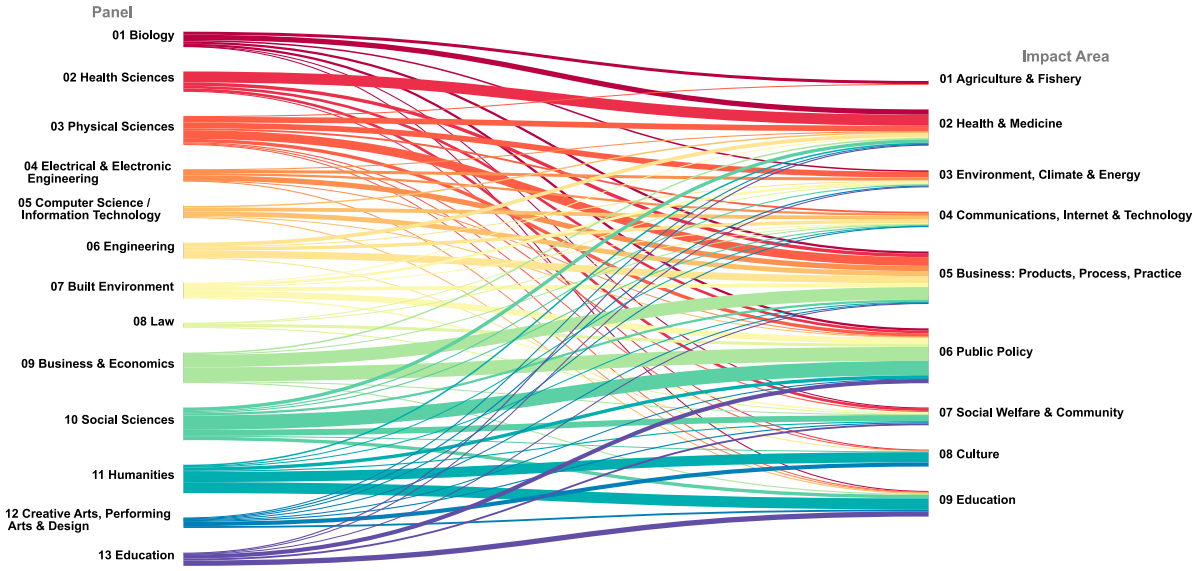


Diagram 4: Alluvial diagram linking panel areas to impact areas

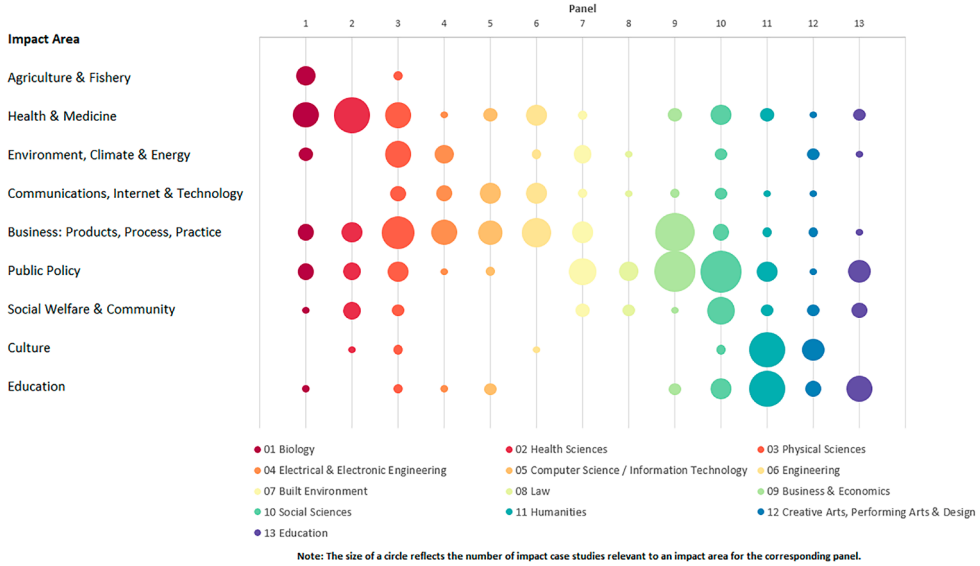
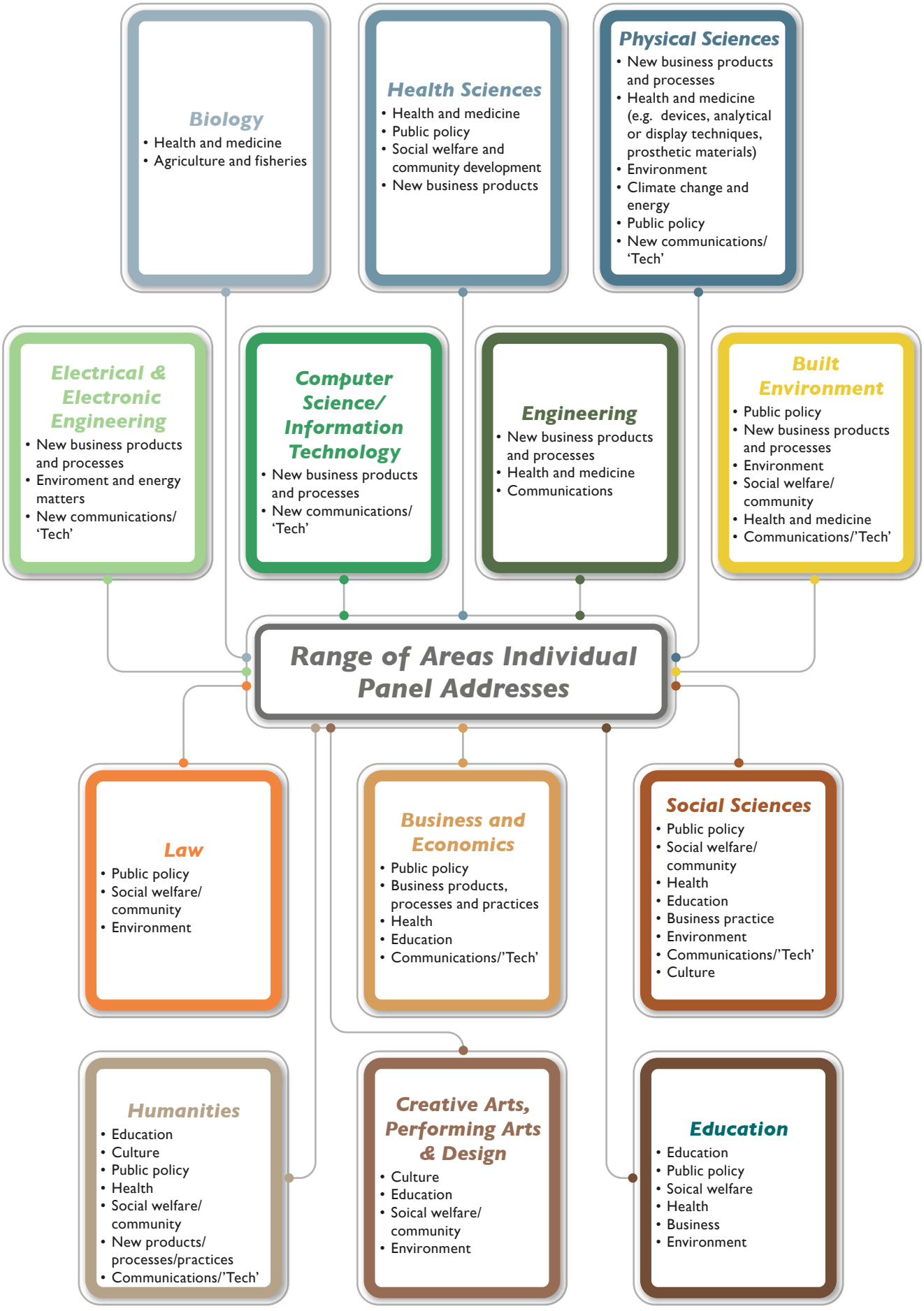


Diagram 5: "Hot spots" illustrating distribution of impact areas by panel


Biology
• Health and medicine
• Agriculture and fisheries
Health Sciences
• Health and medicine
• Public policy
• Social welfare and community development
• New business products
Physical Sciences
• New business products and processes
• Health and medicine (e.g. devices, analytical or display techniques, prosthetic materials)
• Environment
• Climate change and energy
• Public policy
• New communications/ 'Tech'
Electrical & Electronic Engineering
• New business products and processes
• Enviroment and energy matters
• New communications/ 'Tech'
Computer Science/ Information Technology
• New business products and processes
• New communications/ 'Tech'
Engineering
• New business products and processes
• Health and medicine
• Communications
Built Environment
• Public policy
• New business products and processes
• Environment
• Social welfare/ community
• Health and medicine
• Communications/'Tech'
Range of Areas Individual Panel Addresses
Law
• Public policy
• Social welfare/ community
• Environment
Business and Economics
• Public policy
• Business products, processes and practices
• Health
• Education
• Communications/'Tech'
Social Sciences
• Public policy
• Social welfare/ community
• Health
• Education
• Business practice
• Environment
• Communications/'Tech'
• Culture
Humanities
• Education
• Culture
• Public policy
• Health
• Social welfare/ community
• New products/ processes/practices
• Communications/'Tech'
Creative Arts, Performing Arts & Design
• Culture
• Education
• Soical welfare/ community
• Environment
Education
• Education
• Public policy
• Soical welfare
• Health
• Business
• Environment

Biology (including environmental biology, biotechnology, agriculture and food science, and veterinary studies) showed a strong focus in health and medicine. It was also the area with the greatest focus on agriculture and fisheries.

Health Sciences (including clinical medicine and dentistry, nursing, optometry, rehabilitation sciences, and other health care professions) showed a very strong focus on health and medicine, with significant impacts also in public policy, social welfare and community development, and new business products.

Physical Sciences (physics, astronomy, materials science & technology, chemistry, earth sciences & other physical sciences (including environmental science), one of the panels with the largest number of submissions, showed a strong focus on new business products and processes, along with health and medicine (e.g. devices, analytical or display techniques, prosthetic materials) and environment, climate change and energy. But these disciplines also impacted across the full range of areas, notably in public policy and in new communications/'Tech' areas.

Electrical & Electronic Engineering showed distinct foci in new business products and processes, and then in environment and energy matters, and in new communications/'Tech' sectors. There was also activity in several other impact areas.

Computer Science/Information Technology was mainly focused on new business products and processes, and on communications/'Tech' sectors, but with some impact also in a few other areas.

Engineering (mechanical, production, textile, aerospace, chemical, biomedical, environmental, nautical, marine) showed its main focus in new business products and processes, and then in health and medicine, and in communications.

Built Environment (civil engineering, building technology, architecture, planning & surveying): largest area of focus was public policy, followed by new business products and processes, and then environment etc, followed by social welfare/community, health & medicine, and communications/'Tech'.

Law had its main focus on public policy, followed by Social Welfare/Community and environment etc.

Business and Economics, the panel with the largest number of submissions in the RAE, showed strong foci on public policy and business products, processes and practices, with much less pronounced volumes of impact in health, education and communications/'Tech'.

Social Sciences (psychology, political science, geography, sociology & anthropology, social work & social policy, communications & media studies), also a large panel, showed a very strong focus on public policy, followed by social welfare/community, and then health, education, business practice, environment etc, communications/'Tech' and culture – ranging therefore very widely in its impacts.

Humanities (Chinese language & literature, English language & literature, translation, linguistics & language studies, history, area studies, philosophy, and religious studies), the last of the panels with larger number of submissions, had very strong foci in education and culture (the dominant contributor to this last), with lesser contributions to public policy, health, social welfare/community, new products/processes/practices and communications/'Tech'.

Creative Arts, Performing Arts & Design unsurprisingly had its strongest focus in Culture, followed by education, and then social welfare/community and environment, and some impact in most other areas.

Education (physical education, education), finally, had its strongest foci, unsurprisingly, in education and public policy, but with significant contributions in social welfare, and then health, business …. and environment etc.

In summary, while each panel had one or two main foci of impact, most panels also saw work that reached most or all impact areas; and almost all impact areas were impacted upon from most or all panel areas.

07 13 Illustrative Case Studies

We end this report with summaries of 13 case studies, one in each panel area, chosen to illustrate further the range of research impacts achieved by Hong Kong universities.

PANEL	CASE STUDY TITLE
Biology	Controlled soil drying enhances yield and saves water in rice production
Health Sciences	Discovery of novel coronaviruses with public health significance
Physical Sciences	Colloidal Plasmonic Metal Nanocrystals: a new page in food safety and various photonic applications
Electrical & Electronic Engineering	High performance antennas for wireless communication
Computer Science / Information Technology	Protecting billions of stakeholders from critical security vulnerabilities in single sign-on (SSO) and mobile payment systems via scalable security testing and code analysis
Engineering	Motion capture and assistive systems
Built Environment	Enhancing construction workers' health and safety in hot weather
Law	FinTech for financial inclusion: a strategy for digital financial transformation
Business & Economics	Promoting competition policy development and effective enforcement of competition laws in Hong Kong and Mainland China
Social Sciences	Better responses to Youth-at-Risk
Humanities	Social origins of students at elite universities in China
Creative Arts, Performing Arts & Design	Transforming design management capability in the manufacturing industry and influencing national design policy in Mainland China
Education	The inclusion of green skills into policy, TVET teaching and learning in the Asia-Pacific region

Biological Science

- Rice Production
- Water-saving Irrigation
- Economic Return
- Agricultural Education

1. Biology

Controlled soil drying enhances yield and saves water in rice production

Rice growth requires enormous volumes of fresh water – 2,500 litres per kilogram of rice grains. One third of the world's fresh water is used to irrigate rice, and half of fresh water supplies in Asia have been used for rice production. This massive use of water therefore represents a major global challenge.

The lead investigator's research focuses on plant water stress. It derives from his own experience in the 1970s of problems arising from variable irrigation on his family's small rice plot in Jiangsu Province. Studies were conducted jointly with a university in Mainland China where field experiments were feasible (unlike in Hong Kong), and established conditions under which reduced irrigation could result in increased yields of grain. Further work established the underlying biochemical mechanisms, and began analogous investigations of the use of water-saving irrigations on other crops.

This research led to the development of the Alternate Wetting and Drying irrigation technique for practical use during the entire rice growing season. Unlike other rice growing techniques, the understanding of the mechanisms behind the irrigation controls emphasised the importance of controlled soil drying after flowering. The team worked out many practical steps that could be easily implemented by farmers to control the appropriate level of soil drying, such as soil colour changes, sizes of cracks, and hardness of soil (tested by visibility of footprints or not). A simple device using a PVC tube with many side holes inserted into a paddy field was developed to gauge soil dryness from inspection of marks on the walls of the tube.

The team rolled out these techniques via the agricultural extension service of Jiangsu Province, training farming technicians who then cascaded the techniques to millions of farmers. (Although the approach was patented, it was rolled out free to the farmers). By 2016, about 1.25 million hectares of rice fields in Jiangsu had adopted these techniques, accounting for over half the acreage in the province. With this came a huge economic return. During the five years from 2012 to 2016, 3.73 million hectares were managed in this new way, and an estimated increase of RMB 4.6 billion in farmers' incomes resulted from higher rice yields and lower irrigation costs.

Further benefits came from the change away from the traditional practice of maintaining a steady level of water in the paddy field for virtually all the production time. For example, a dry field is more accessible to harvesting machines, allowing an earlier harvest. A less humid canopy also alleviates problems with rice diseases and pests.

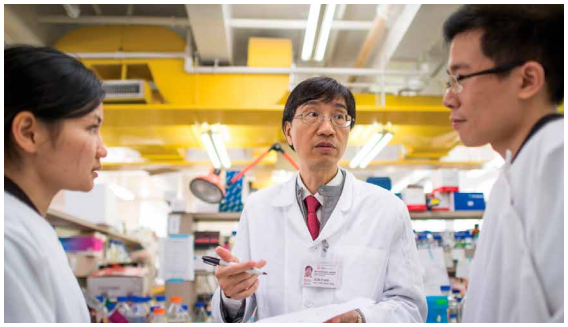
Clinical Medicine

- Commerce & Industry (Diagnostic Kits)
- Healthcare & Patients
- Health Policy
- Education

2. Health Sciences

Discovery of novel coronaviruses with public health significance

During the SARS epidemic in 2002-03, researchers at this university were the first in the world to discover SARS-CoV-1 and developed rapid diagnostic tests. They also discovered its ancestral virus, the bat SARS-related CoVs in Chinese horseshoe bats, which subsequently turn out to be ancestrally related to SARS-CoV-2 of 2019. They have since taken a leading position in the discovery of novel coronaviruses, including Human CoV-HKU1 and more than 30 CoVs in bats and other animals, a number of which later proved to be closely related to emerging CoVs causing new epidemics. Further work identified the mechanisms through which these viruses infect hosts, developed diagnostic tests, and showed that novel genotypes can emerge through recombination. Work on MERS-CoV included discovery of the Bat CoV-HKU4/5 which are closely related to MERS-CoV, and its effective antiviral treatment. In 2006 the team also discovered Bat CoV-HKU2 and predicted its potential for interspecies transmission which was later reported to cause pig farm fatal diarrheal outbreaks in piglets. From all this work they have laid down an unprecedented phylogenetic map and evolutionary model for CoVs.



This work on the discovery of novel coronaviruses, identification of their animal sources, and development of diagnostic kits, has had considerable global health and economic impacts. These fall into four categories:

a) *Commerce and industry:* numerous rapid diagnostic kits were developed by companies, working with the team's results. One such can detect 18 viruses and 4 bacteria within 45 minutes. Sales of these kits have risen sharply, as have the number of customers and their global distribution, and the resulting revenues. One company expanded its workforce from 310 in 2013 to 800 in 2018.

b) *Healthcare services and patient benefit:* antiviral treatments and diagnostic kits arising from this research are now in use in hospitals in several continents.

Clinical Medicine

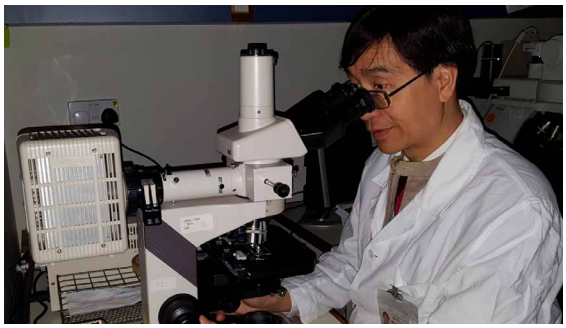
- Commerce & Industry (Diagnostic Kits)
- Healthcare & Patients
- Health Policy
- Education

2. Health Sciences

Discovery of novel coronaviruses with public health significance

c) *Health policy:* the tracking of SARS origin in animals provided crucial guidance to public health measures internationally in segregating the animal carriers from humans, introducing continuous surveillance of animal viruses, and identifying potential emerging zoonotic viruses. Experience gained of antiviral treatments similarly underpinned disease control measures not only in Hong Kong but internationally. In addition, without the team's foundational work on SARS and bat coronaviruses, the rapid identification and accurate diagnosis of MERS-CoV after its emergence in 2012, similarly for COVID-19, and prompt implementation of public health policies in 2013 and 2019 would not have been possible.

d) *Education and public understanding of science:* Members of the team have engaged actively in a wide range of advisory roles, with direct influence on international and local protocols for, e.g., promoting personal and environmental hygiene and good travel advice. Extensive media activity has raised public awareness of all aspects of CoV transmission and control. Secondary school teachers and students, in particular, have found presentations on these matters impressive and helpful.



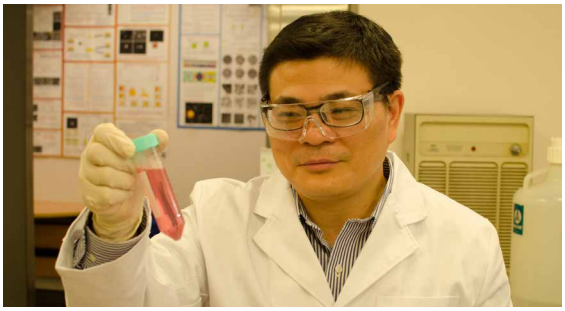
Physics

- Economy
- Food Safety, Photonic Applications
- Optical and Optoelectronic Devices
- Medical R&D, Diagnostics & Biotechnology

3. Physical Sciences

Colloidal Plasmonic Metal Nanocrystals: a new page in food safety and various photonic applications

The case study centres on work on the synthesis of very pure noble metal nanocrystals with exquisitely controlled geometric shapes and sizes. By combining several approaches, the research team was able to synthesise highly pure plasmonic nanocrystals with responsive wavelengths that could be accurately tuned with high precision, and span the visible to the infrared region. Products derived from this technology have reached over 1000 customers in more than 30 countries and regions, and have had impacts upon the economy, medical R&D, diagnostics, biotechnology, and optical and optoelectronic devices.



The practical applications of these nanocrystals include:

a) *Smart tags* that can encode their thermal history via colour changes over time. These can be tuned to make customised and highly sensitive time-temperature indicators for the quality of food, medicine and other perishable products and for monitoring their thermal history during storage and transport.

b) *Molecular detection with portable spectrometers:* Plasmonic metal nanocrystals focus light into nano-scale hot spots around the nanocrystal. These can be designed to target specific molecules, and amplify their Raman signals strong enough to allow the detection with portable spectrometers. By thus pushing molecular detection efficacy to a level at least an order of magnitude better than conventional methods, it is possible to develop low-cost detection for different application situations in foods, beverages, drugs and explosives.

Physics

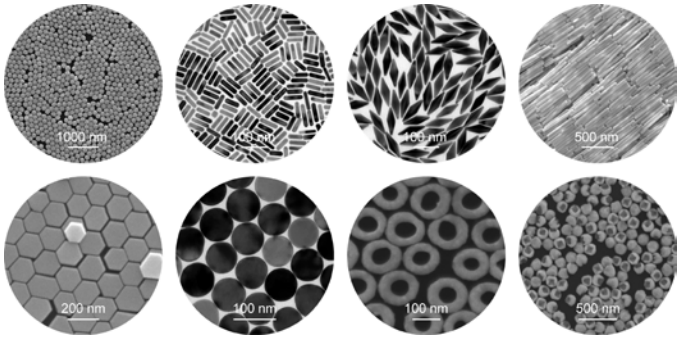
- Economy
- Food Safety, Photonic Applications
- Optical and Optoelectronic Devices
- Medical R&D, Diagnostics & Biotechnology

3. Physical Sciences

Colloidal Plasmonic Metal Nanocrystals: a new page in food safety and various photonic applications

Since 2011, the first of the associated spinout companies has been producing low-cost, reliable and uniform nanocrystal products that have been widely adopted by research institutes from over 20 countries and regions. The products are also sold to nearly every major university and research institute in mainland China. A second spinout company, founded in 2014, is commercialising Smart Tags. A third was founded in 2018 to develop refined low-cost detection methods for additives in food and beverages, and pesticides on fruits and vegetables.

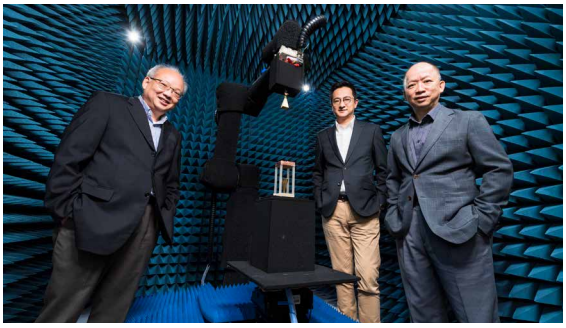
Applications have also been found in breast cancer imaging, and other biomedical purposes. And finally, this work has been the subject of active media presentations, and exhibitions such as InnoCarnival 2018 and the International Exhibition of Inventions, Geneva.



- Antenna Technology
- Mobile & Wireless Communications
- Global 5G Network
- Navigation Satellite System

4. Electrical & Electronic Engineering

High performance antennas for wireless communications



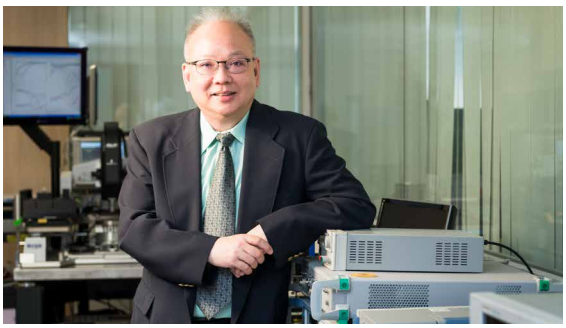
The case study derives from work by a team who, over several decades, have pioneered the design of microstrip antennas, small antennas, dielectric resonator antennas, and complementary antennas, all of which have been widely applied in mobile and wireless communications. These applications include: capacity to build antennas which can function versatilely under many different operating conditions, for use in the base stations of mobile communication systems, Wi-Fi hotspots, RFID readers, and radar systems; invention of glass antennas and water patch antennas for transparent electronics and flexible electronics; and magneto- electric dipole antennas for 5G base stations and mobile phones, imaging radars for driverless cars, and millimetre-wave identification.

More specifically, the case study focuses on:

a) Significantly improved antennas for the 3G mobile communication service. This led in 2002 to a spin off company which sold tens of thousands of base station antennas and was one of the earliest companies on base station antennas in China.

b) Subsequent development of microstrip antennas and magneto-electric dipoles suitable for use in 5G networks, and applied globally.

c) Small circularly polarized patch antennas (avoiding the previous need for expensive high dielectric constant materials) which were applied to the receiving terminals of the BeiDou Navigation Satellite System of China, via a spinoff company set up in 2002. The first batch of these BeiDou mobile terminals was used by the rescue crews at the Sichuan earthquake in 2008, allowing immediate reporting of the location of victims. The company continues to grow, and its equipment now features in thousands of parts of portable terminals and devices for the BeiDou Navigation Satellite System.

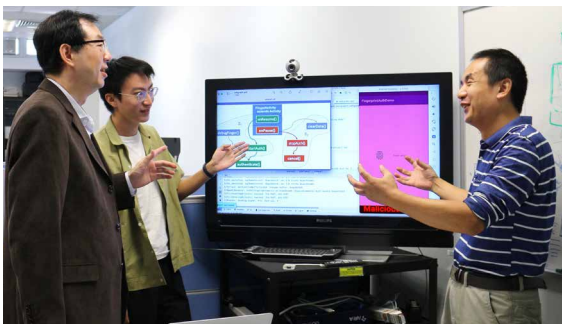


Computer Science/ Information Technology

- Single-sign-on & Mobile Payment Systems
- Cybersecurity
- Security Testing/Analysis
- Authentication for Mobile Devices

5. Computer Science/Information Technology

Protecting billions of stakeholders from critical security vulnerabilities in single-sign-on (SSO) and mobile payment systems via scalable security testing and code analysis



Single-sign-on and mobile payment systems are ubiquitous in our digital world, but they bring significant security risks. On-line service providers have developed all-in-one platforms offering services spanning social networking, entertainment, communications, e-commerce and mobile payment. Each platform embraces millions of outside merchants or developers.

A typical transaction involves the Identity Service Provider (e.g. social media), a 3rd party service/mobile application provider (e.g. travel booking apps), and the end-users/customers, who can conveniently use their identity account with the first of these to conduct business or make payments with the second without needing a further account. To manage these complex interactions, Multi-Party Distributed Authentication/Authorization Frameworks have been adopted.

However, the rapid adoption of Single-Sign-On and mobile payment services has resulted in a proliferation of insecure implementations due to (i) the inherent technical challenges of realizing fool-proof security for multiple parties , and (ii) the introduction of numerous 'home-brewed' platform specific modifications to the Framework.

To tackle these problems, an Information Engineering team developed a series of new techniques for large scale systematic security testing and for detecting vulnerabilities in payment systems. Two examples of what they found are:

a) Widespread, inadvertent leakage of critical secret-keys from apps and mobile payment merchants; and
b) A threat on the QR-code generation/scanning process at a mobile payment service which allowed hijacking of security critical information.

Computer Science/ Information Technology

- Single-sign-on & Mobile Payment Systems
- Cybersecurity
- Security Testing/Analysis
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5. Computer Science/Information Technology

Protecting billions of stakeholders from critical security vulnerabilities in single-sign-on (SSO) and mobile payment systems via scalable security testing and code analysis

The team have open-sourced their suite of security testing/analysis tools for free use by cybersecurity practitioners. They also alert service providers to problems. For example, one tool identified 75 popular apps (with total downloads exceeding 2.4 billion) as vulnerable to hijacking of victims' travel itineraries, private messaging archives, financial records, photos, and viewing and shopping histories. They made a 'responsible disclosure' to the Identity Service Provider, who promptly updated their protocols, alerted all their 3rd party users, and provided fixes. Re-testing the apps found that most had promptly fixed the problem.

The case study gives several other similar examples, all affecting huge numbers of users, and reports that the team's work also influences the setting of international standards on authentication for mobile devices.

6. Engineering

Motion capture and assistive systems

This case study turns on a combination of technologies developed in an engineering department:

a) smart actuators for assistive knee braces and robotic exo-skeletons for people with mobility problems. A novel magnetorheological actuator was developed, able to work as a clutch or a brake, and with high energy efficiency. As a clutch, it enables an electric motor to transfer torque to the leg; as a brake, it provides controllable passive torque; and

b) a novel method for real-time and convenient modelling and evaluation of human gait, in order to support rehabilitation.

Combining the two, a fuzzy expert system was developed. This takes the patient's physical condition and gait analysis results as inputs, and derives suitable levels of different assistive functions of the knee braces. During clinical pilot studies, control strategies based on this combination of technologies were tested and found to be able to provide effective assistance during gait rehabilitation.

From this position, in 2012 a startup company was established to further develop the motion capture paradigm, and supplied over time with PhD graduates from the Department. The company now has more than 300 employees, with establishments in China and the USA. After further equity financing in 2016, the company moved to develop the world's most affordable, adaptable and versatile motion capture system. As well as its use in intelligent rehabilitation equipment to connect doctors and patients, it has also been used in films (Game of Thrones), and for training golfers (used by 60% of USA PGA top 100 coaches). A scalable commercial VR version has been developed for multi-users with physical props and motion capture. This was used in NASA's commemoration of the 50th anniversary of the Moon landing.

The company is planning to establish offices and labs in both Hong Kong and Shenzhen to further enhance its collaboration with the university.

Civil Engineering/ Material Science

- Product Manufacturing
- Construction Industry
- Cleansing, Gardening, Logistics
- Occupational Health

7. Built Environment

Enhancing construction workers' health and safety in hot weather

At least 75 construction workers in Hong Kong suffered injury or death from heat stress conditions between 1998 and 2013.

A multi-disciplinary team from the submitting university, plus partners at another Hong Kong university, and others in Mainland China and the UK, has pioneered a series of heat stress research projects since 2010 to address these issues.

The work involved evaluation of fabric types coupled with developmental work on fabrics and ergonomic design; and a novel approach to occupational intervention research which moved beyond randomised control trials in laboratory settings to include also field experiments and a field survey of construction workers.

The pathway to impact involved engagement of stakeholders from the early stages, and participation in a variety of promotion and exhibition activities.

Among the outputs from the research is an anti-heat stress working uniform which offers around 29% reduction in heat storage and more than 14% improvement in thermal comfort. Attention was given to reducing the garments' retail price to aid take-up. The detailed evidence-based garment specification emerging from this work has also led to changes in working practices, replacing earlier looser guidelines.

The uniform was licensed to the Construction Industry Council in 2015 (for a nominal HK$1) and was specified by the Hong Kong Government as standard work wear for all public contracts in 2018. Over 116,000 anti-heat stress shirts and 36,000 pairs of trousers have been sold to over 100 organisations to date. The garments are also being adopted for other work sectors such as cleaning, gardening and logistics in Hong Kong, Macau, Cambodia and Saudi Arabia.

8. Law

FinTech for financial inclusion: a strategy for digital financial transformation

The case study summarised here concerns the development within a Faculty of Law of a strategy to use financial technology (FinTech) to support digital financial transformation in developing countries to increase financial inclusion and support sustainable development.

Across the world, as of 2018, over 1.7 billion people lacked access to a bank account or mobile money account, severely constraining their ability to connect to the financial and economic systems as part of wider personal and social development. Research done between 2012 and 2018, focusing on Hong Kong's role as an international financial centre, examined the technological changes that were transforming finance around the world, particularly in the context of digitalisation and datafication of global financial markets, the emergence of a major wave of new FinTech startups, transformations taking place in China and other countries, and the emerging role of large technology companies in finance. It further identified regulatory challenges arising from these new trends and analysed the use of technology not only for financial regulatory compliance but also to build better regulatory and financial systems.

On the basis of this research, the team were invited by the Alliance for Financial Inclusion (AFI), an international organisation made up of central banks and regulatory authorities from more than 90 countries in 2017 to analyse the role of FinTech in supporting financial inclusion around the world. This work focused on how 1.2 billion people from 2010 to 2018 had entered the financial system for the first time through a bank or mobile money account. The majority of these people were in Kenya, China, Russia and India.

From analysis of these and other cases, the team devised a strategy based on 'four pillars' which underpin digital financial transformation, with the potential to support very rapid improvements not only in financial inclusion but also other financial sector objectives, such as financial stability, market integrity and market development. This strategy was adopted by the AFI at its meeting in Sochi in September 2018, followed by adoption by the Intergovernmental group of 24 (G24), the World Bank and the IMF a month later, and then promoted by the AFI at regional meetings around the world. It has been adopted by more than 90 central banks and other regulatory authorities. The team is now supporting the AFI in implementation of the strategy, and assessing its impact.

9. Business and Economics

Promoting competition policy development and effective enforcement of competition laws in Hong Kong and Mainland China

This case arises from work in a business and economics research group that has for over 20 years been addressing issues of competition policy in Hong Kong and Mainland China, influencing competition policy debate, design and enforcement as a result.

The underpinning research includes:

a) the strategic behaviour of firms in innovation, vertical spinoffs and vertical integration, which has provided insights into how antitrust authorities should assess such business strategies;
b) how pricing strategies can significantly foreclose competition and hurt consumers; and
c) a comprehensive policy analysis that generated concrete recommendations to the Hong Kong SAR during its deliberations on the Competition Ordinance of 2012.

This research has been highly influential in the policy making and regulatory processes in Hong Kong and Mainland China. For instance:

a) In 2010, preparing reports for the Anti-Monopoly Bureau of the Ministry of Commerce, PRC, on state-of-the-art antitrust laws and 'best practice' in the major developed economies, and proposals on merger guidelines for China. These impacted on subsequent merger reviews under competition law, and underpinned new Chinese regulations on 'Assessing the competition impacts of concentrations among undertakings' that were introduced in 2011 and have been applied to over 3000 mergers.
b) In 2016, preparing a commissioned report for the Hong Kong Competition Commission on behavioural and structural issues that were hindering competition in the local auto fuel market, which provided the basis for the reintroduction of cheaper fuel into Hong Kong;
c) Leading a team that since 2016 has been conducting economic analysis for an investigation of a global top-5 multinational corporation for alleged violation of China's Anti-Monopoly law, on which a conclusion was awaited at the time of submission of the case study.

A final mode of impact takes the form of energetic action to make anti-trust materials available to non-English speaking Chinese experts by leading a team of anti-trust economists to translate key sources, thus supporting the build-up of a body of expertise during the first decade of operation of anti-monopoly legislation in China.

Social Science

- Youth & Family Services
- School Support Network
- Community Support

10. Social Sciences

Better responses to Youth-at-Risk

This case study describes how research into welfare responses to street youth, and restorative approaches to school delinquents, has been brought together to aid the governments of Hong Kong, Macau, Singapore and Guangzhou to respond effectively to the needs of at-risk youths, in contrast to more traditional measures based on court interventions and institutionalised sanctions.

Research into street youths explored the channels through which they were 'Triadized' and assimilated gang values. It identified modes of outreach work and community support that could channel the youths' energies into more constructive goals, such as participating in volunteer services in the community, thus providing an alternative sense of belonging and achievement.

Research into school delinquency, with the risk of dropping out, leading to life on the street, identified a strategy called 'Restorative Whole School Approach', based on tolerance and acceptance, combined with appropriate social disapproval of delinquency and mediation tactics. Trials, such as a two-year longitudinal study involving nearly 1200 high school students, found a significant reduction in bullying, increased empathy, and higher self-esteem in schools that applied the new approach compared with those that did not.

These approaches were developed, adopted and applied over a number of years in Macau, Singapore, Guangzhou and Hong Kong.

10. Social Sciences

Better responses to Youth-at-Risk

Among the activities involved were:

a) Developing for the Macau Government a youth service blueprint which, after initial trials, was implemented on a permanent basis. In one pillar of the programme, in 2015, 30 social workers and 30 police superintendents were trained to work with police-cautioned youths. In another, in 2018 about 13,000 service recipients benefited from new Community Youth Work Teams. In a third, also in 2018, 53,000 recipients benefited from new Integrated Youth and Family Service Centers.

b) Supervision of social workers in Hong Kong for 6 years, funded by government, aimed at building a positive discipline-oriented school support network and cultivating an anti-bullying culture among youth, together with preparation of practitioners' guidelines and tools. As a result, nearly 15,000 students, over 2000 parents, and nearly 3000 teachers were assisted over the 6 years.

c) Training 200 outreach workers and providing advice to authorities in Guangzhou to consolidate a service model for at-risk youth that benefited nearly 20,000 young people in 2019.

d) Providing advice to the Singapore Government to develop a service model for at-risk youth and training 40 outreach workers in youth gang work, such that at least 200 at-risk youth were assisted by 2019.

e) In parallel, developing collaboration between Hong Kong practitioners and those in the other locations, and promoting wider community and international awareness of these programmes.

11. Humanities

Social origins of students at elite universities in China

Historians at this university have developed and made available for the first time an empirical basis for assessing how, over time, China's national college entrance examination (*gaokao*) made elite university education accessible to children from modest origins. They did this through large scale quantitative analysis of more than 150,000 student registration records at two major Chinese universities over more than 50 years.

The underpinning research stems from the early 2000s, with a study of the social origins of students at Peking University, an elite national university of China, and Suzhou University, a major regional university, over the last half of the 20th century. A team was assembled from the submitting university, together with collaborators at another Hong Kong university, UCLA, and Peking University, who turned student registration records at both universities into a database that they then used to analyse trends in the geographic origin, family backgrounds, and gender of 64,000 students from Beijing and more than 86,000 from Suzhou.

They found that up to 2002, when the database ends, and well into the period of China's economic reform and opening, one quarter to one third of students at both universities came from farming or manual origins. While in the final years covered by the study, rising numbers of students were the offspring of professionals, managers and other white collar workers, it was clear that students from such privileged backgrounds had not monopolized places at the elite universities, unlike in the United States and United Kingdom. The study also pointed to certain characteristics of school provision as underlying factors in producing this outcome. The large scale, and complex and laborious coding and transcription, of the registration data, overcame a number of shortcomings with previous analyses of this issue.

11. Humanities

Social origins of students at elite universities in China

This work appeared at a time of heated public debate about college admissions in China and the role of the entrance examination, with active discussion of possible alternatives. It filled a major gap in providing reliable evidence on how the *gaokao* system worked in practice. It was taken up in policy debates, reaching Politburo level, and even the Vice-Premier. The attention given to the work by senior policy makers was reported in China Youth News Online, the official online platform of the Communist Youth League, which at that time had 100 million members.

As the case study cautiously observes, 'While in the light of the opacity of the Chinese leadership's decision- making processes, it is not possible to assess whether … [the study] … had a direct impact on college admissions policy', circumstantial evidence based on how the policy debate unfolded (including a conclusion in line with the implications of the research) suggests that it was taken into account. It is also clear that the study informed a great deal of public debate, becoming the focus of numerous discussions and critiques in non-academic venues, particularly the media.

Design

- Design Management & Policy
- Design Business Ecosystem
- Digital Creative and Manufacturing Industries
- Pollution Reduction in Furniture Industry

12. Creative Arts, Performing Arts & Design

Transforming design management capability in the manufacturing industry and influencing national design policy in Mainland China

This case arises from a Design group that regards its research as strongly relevant to the work of various Hong Kong and Chinese government departments, industries (which invest in or commission over 50% of their research), cultural institutions in Hong Kong and internationally, non-governmental organisations, and professional organisations which apply their research to enhance their support to industries and communities with special needs for design and innovation.

Practice in design management that embraces design operation, as well as organisational and strategic management, and that was well established in, e.g., the UK and Japan, was slower to take root in China. These researchers began in the 2000s the first detailed empirical study of the practice of design management in China. It included around 50 case studies and data from 330 manufacturers. In 2012 they reported their findings, together with a framework for moving Chinese capability forward from a model in which design was confined to the work of the professional designer and towards one in which design management plays a more central role in innovation throughout the business ecosystem.

This work informed national level design policy in Mainland China and Hong Kong over the succeeding years.

Before 2015 there was neither national design policy especially for the manufacturing sector, nor policy promoting design and innovation that embraced the knowledge economy in China. This group was invited in 2013 to join the *Strategic Research on Innovation Design* project of the Chinese Mechanical Engineering Society, funded by the Chinese Academy of Engineering. Its design management framework was used to explore the new role and scope of design in the knowledge economy and to define the scope of innovation design and its development path. This work was incorporated in 2015 into the Chinese government's *Made in China 2025* ten year strategy for upgrading Chinese manufacturing innovation capability. Further invitations followed for work on drafting policy guidelines on *how* to implement the design policies in *Made in China*, later distributed to all manufacturing companies across China, and for contributions to the national strategy around digital creative industries and, in 2017, the guidelines for evaluating the quality of international collaborations, products and stakeholders under the *One Belt One Road* initiative.

Design

- Design Management & Policy
- Design Business Ecosystem
- Digital Creative and Manufacturing Industries
- Pollution Reduction in Furniture Industry

12. Creative Arts, Performing Arts & Design

Transforming design management capability in the manufacturing industry and influencing national design policy in Mainland China

More specific economic impacts were also achieved through work as part of a drive by the Guangdong government to transform their increasingly unviable high pollution, high waste and low technology furniture industry.

Two test cases were selected. In the first, after implementing a new business model which significantly improved production performance and enabled customers to buy direct from the manufacturer, benefiting from rapid delivery of customised products at mass-production prices, a home furniture firm saw its annual sales increase by 400% between 2014 and 2018, reaching RMB 6.6 billion (HK$ 7.3 billion). In the second case, an office furniture systems manufacturer, sales revenue grew 70% from 2014 to 2018. The new business model reduced the traditional construction time from 200 to 67 days, compressing five stages into two. Environmental improvements were also made by adopting a modular approach (standardised units increasing the scope for re-use), and using new materials which eliminated harmful formaldehyde emissions.

13. Education

The inclusion of green skills into policy, TVET teaching and learning in the Asia-Pacific region

Education researchers at this university work in an environment of long-established collaborations with education providers, government agencies, and non-governmental organisations in Hong Kong and widely internationally.

This case study concerns the need in the Asia-Pacific region for the skills to implement and sustain low-carbon economies (Green Skills) and led directly to corresponding changes in policy and educational practices in technical vocational education and training (TVET) in numerous countries.

It began from a project funded by the Asia Development Bank (ADB) from 2012 to 2014 to map existing practices on green skills in TVET in Indonesia, India, Sri Lanka and Vietnam against demand in construction, transport, energy and hospitality industries. This resulted in three ADB briefs that provided policy directions for Developing Member Countries. Further work for UNESCO led to a framework for conceptualising generic green skills – the first of its kind – to ensure these skills are included in the TVET curriculum.

The expertise acquired from this work led to invitations to contribute to the strategic development plans of international organisations, such as the ADB and the regional training programme of the Colombo Plan Staff College, through the latter of which all 16 member countries now focus on greening concepts and competencies in training programmes for TVET staff. Similarly at national level, invited work has led to new programmes in, e.g., Malaysia (where the developing framework is expected to impact over 1000 TVET institutions), Mongolia, and Nepal (with revised curricula and occupational skill standards focusing on occupations such as auto-mechanics, solar photovoltaic technicians, hospitality management and agro-forestry). Analogous work for the Chinese Ministry of Education produced reforms to China's TVET programmes, where more than eight providers have reformed their curricula to include green skills in seven specialties.

Acknowledgement

The alluvial and hot spots diagrams used in the report are inspired by The Policy Institute, King's College London: Impacts of academic research from Welsh universities, May 2017.
(https://www.learnedsociety.wales/wp-content/uploads/2017/06/The-impacts-of-academic-research-from-Welsh-universities.pdf)

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Evidence from the Research Assessment Exercise 2020

A summary report by
Professor Philip Gummett, RAE 2020 Consultant
Commissioned by the University Grants Committee
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