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

The impact of research undertaken by universities in Hong Kong

A synthesis of the RAE 2020 impact case studies

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This report is part of a series of outputs that examines the impact of research arising from eight universities based in Hong Kong and funded by the University Grants Committee (UGC). The report focuses on the Impact Case Studies (ICS) produced by the UGC-funded universities as part of their response to a Research Assessment Exercise (RAE) in 2020. The overarching report - *The impact of research undertaken by universities in Hong Kong: A synthesis of the RAE 2020 impact case studies* – is accompanied by 11 thematic reports that examine the nature of research impact in different areas, ranging from Arts & Culture to Health & Healthcare. The 342 impact case studies that are analysed through this body of work are also available on a searchable database that is posted on the UGC's website.

Executive summary

The University Grants Committee (UGC) conducted a Research Assessment Exercise of its eight UGC-funded universities in 2020 (RAE 2020). Part of the RAE included the assessment of research impact, through the submission of 345 Impact Case Studies (ICS) by universities. This report provides a synthetic analysis of the 342 publicly available ICS and is accompanied by a searchable database of the ICS and 11 thematic reports describing the nature of the social impact in more depth.

Four key observations emerged from the synthetic analysis of the 342 ICS

01

Universities in Hong Kong make a significant contribution to society

The ICS capture a great diversity of impact across the research spectrum and within thematic areas. More than one type of change may be affected by any one piece of research. Social sciences contributed particularly to impacts that effected change in policy and governance while public debate and changed perceptions were influenced primarily by research in the arts and humanities, education and social policy. Science and technology contributed to economic change through innovative research and its development via licences, companies and products. Changes to processes and practice were influenced by the most widespread range of research. Some notable examples of impact include:

- HK$13 million (US$ 1.6m) savings to public health system in Hong Kong due to development of a non-invasive test for liver fibrosis
- 20 million people watched televised lectures on East-West cross-cultural understanding and misconceptions
- 20,000 teachers and students benefited from a model for teaching meditation to students and educators in secondary schools
- 25 million kilowatt-hour annual savings (worth HK$25m) from optimised design of air conditioning systems, the integration of renewable energy and smart, energy efficient control strategies
- 4,270 (estimated) children avoided toothache due to the development silver diamine fluoride (SDF) solution to manage tooth decay
- RMB4 billion (US$600m) increase in farmer's income in Jiangsu Province due to the adoption of Alternate Wetting and Drying (AWD) irrigation technique during the entire rice growing season
- US$1.5 billion annual revenues for entecavir (BaracludeTM), a drug tested by Hong Kong researchers as an alternative treatment for hepatitis B
- US$2.83 billion annual revenues for DJI Drones in 2017, a company started by a Hong Kong university Master's student based on the research undertaken as part of his studies

02

The social impact of research benefits communities in Hong Kong and globally

Three quarters of the ICS described benefits that were being realised in Hong Kong. It was possible to map these benefits using the Hong Kong Standard Industrial Classification, illustrating how they concentrate in thematic areas. For example, Engineering, Energy & Construction had a more widespread impact across construction (42%), logistics & transport (28%) and energy (17%). Production & Technology transfer influenced manufacturing (50%), information and communication services (27%), and health & social sector (27%). Whilst two-thirds of the 25 Environment & Conservation ICS benefited environmental management and more than half of the Information Technology ICS benefitted Information and communication services, as well as influencing economic and health sectors.

Around two-thirds of the impact described in the ICS is realised in Asia, predominantly in the Asia-Pacific region. The other two continents gaining a significant impact benefit are Europe and North America and this matches the regional spread of both academic and pharmaceutical/industrial collaborative partnerships identified by the researchers. The distribution of impact by region is a broad reflection of, first, global research excellence as well as regional proximity and, second, the accessibility and likelihood of potential research and development partners. It is evident that Hong Kong is a frequent research partner in those regional economies that have a well-established reputation for research excellence (Singapore, Australia, Japan and South Korea). These partnerships will be delivering high quality research outcomes and this amplifies the impact of Hong Kong's own research capabilities.

03

The research underpinning social impact is globally outstanding

It was possible to assess the academic, or citation impact, of the research that was cited within the ICS. The average and the median normalised citation scores were calculated for 1,446 papers that were indexed on the Web of Science. The overall average was over four times higher than would be expected. In part this could be a consequence of a general selection of the more highly cited material for inclusion in these ICS, although the overall citation impact of all Hong Kong research was also high (1.8 times what you would expect).

There were a number of truly exceptional papers including five papers in Health & Healthcare and two papers in Information Technology that had received more than 100 times the number of expected citations.

04

The societal impact of research from Hong Kong universities provides the foundations to support the Government's strategic priorities

Evidence derived from the ICS and from the bibliometric analysis shows that the research of Hong Kong's universities is diverse, excellent and well connected and is therefore likely to provide the foundations for supporting the Government's strategic priorities set out in the National 14th Five Year Plan. That is, Hong Kong will continue to enhance its competitive advantages in four existing centres of strength (international financial centre, international transportation centre, international trade centre, as well as centre for international legal and dispute resolution services in the Asia-Pacific region), and in parallel take on four additional "centre" roles (international aviation hub, international innovation and technology hub, regional intellectual property trading centre, and an East-meets-West centre for international cultural exchanges), collectively known as the "Eight Centres".

Research value will best be ensured if universities continue to be able to support these priorities and other areas by: delivering high quality research; supporting high impact research; making use of mechanisms to facilitate multidisciplinary research; and sustaining international collaboration.

Contents

The content and purpose of this report

The University Grants Committee (UGC) conducted a Research Assessment Exercise of its eight UGC-funded universities in 2020 (RAE 2020). This is a report on the context of that exercise, an investigation of the Impact Case Studies (ICS) produced by the universities, and an analysis of their content.

The Hong Kong UGC is an independent and non-statutory body established in 1965 that advises the Government on the funding and strategic development of higher education in Hong Kong. Since 1993, the UGC has conducted six RAEs as a part of its performance-based assessment process. Each RAE assesses the research quality of the eight UGC-funded universities and thus encourages high impact research (see Annex 1 for Background):

- City University of Hong Kong (CityU)
- Hong Kong Baptist University (HKBU)
- Lingnan University (LU)
- The Chinese University of Hong Kong (CUHK)
- The Education University of Hong Kong (EdUHK)
- The Hong Kong Polytechnic University (PolyU)
- The Hong Kong University of Science and Technology (HKUST)
- The University of Hong Kong (HKU)

This report focuses on the ICS produced by the UGC-funded universities as part of their response to RAE 2020, in addition to the quality profiles used to evaluate areas of relative research strength.

For RAE 2020, research impact, in this context, is 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 whether locally, regionally or internationally; and that are beyond academia; and includes, but is not limited to

(a) positive effects on, constructive changes or benefits to the activity, attitude, awareness, behaviour, capacity, opportunity, performance, policy, practice, process or understanding, of an audience, beneficiary, community, constituency, organisation or individuals; or

(b) the reduction or prevention of harm, risk, cost or other negative effects.

There were 41 subject-based Units of Assessments (UoA, reduced from 68 cost centers in the previous RAE 2014) grouped under 13 main panels. RAE 2020 introduced research impact as one of the new assessment elements, so as to encourage research that not only had high academic impact but would also be of broader social relevance with high economic and social benefits. Impact was assigned a 15% weighting within panel ratings of a submission (the other elements were: research outputs - 70%; and research environment - 15%).

About 16,000 research outputs involving some 4,200 eligible academic staff, 345 ICS and 190 research environment submissions were assessed in this exercise. Results and published documents regarding the RAE 2020, including the principles and the methodology, and those of the previous RAEs, are accessible from the UGC website.[1]

There are some specific and technical terms in this report: a glossary lists these in Annex 2. The methodology used by the project team is described briefly in the next section (detail in Annex 4) and the analytical outcomes in subsequent sections. Here, we describe the material that supports this analysis and the report.

The ICS were each four pages in length with five standard sections: (1) *Summary of the impact*; (2) *Underpinning research and its outcomes;* (3) *References to research outputs;* (4) *How research led to impact;* the beneficiaries, nature and timing of impact; evidence of the extent of impact; and the unit's role in impact; and (5) *Corroborating statements for impact claims*.

Underpinning research was required to be within the scope of the relevant UoA at the submitting university and carried out during the period from 1 January 2000 to 30 September 2019. The impact may occur (that is, deliver benefit) in any geographical location whether locally, regionally, nationally or internationally. And, while ICS may describe work at early or advanced stages of development, the impact should occur in the assessment period from 1 October 2013 to 30 September 2019. Finally, ICS must be underpinned by research of at least 2* international standing.

Universities submitted an ICS for each UoA where they had three or more eligible academic staff and numbers of ICS in each UoA increased if the headcount of eligible academic staff exceeded 15. An overview statement describing the submitting unit's general approach to enabling research impact was required in support of each set of one or more ICS describing specific examples of impacts achieved.

The independent peer review panels assessed 80% of the 345 ICS as 'outstanding' or 'considerable' impact (4* or 3* using the quality profile categories). Three ICS were granted exemption from publication, which means that 342 are available for this analysis.

[1] www.ugc.edu.hk/eng/ugc/activity/research/rae.html

The methodology of this study

A more detailed description of the methodology is included in Annex 4.

The study was partitioned into tasks that responded to core objectives identified by the UGC. The UGC wished to: (a) make the ICS submissions freely available for any researcher to carry out analysis; (b) receive a qualitative and quantitative analysis of the ICS, including common themes and messages that evidence the broad impact of research on society; and (c) illustrate research impact under a series of common themes to enhance public understanding of the impact that universities deliver. To this end, the methodology supporting the study is structured as: A – Database development; B – Data mining and enrichment; and C – Reading, coding and analysing.

Task A: Database development

The 342 original ICS PDF documents needed to be converted into a single, uniform dataset that could be accessed for analytical purposes, through a web site. At the same time, the documents needed to be comprehensively annotated, to enhance their value for indexing and reference purposes, and structured in a consistent way, to make the experience of reading and searching easier for the user.

Although the ICS submissions were made via a standard template, the PDF documents collected were not in a structured, machine-readable format. This constrained any automatic display, such as via a web interface, and limited the analytical potential of the data. A key task in database development is therefore the conversion of the original PDFs into a standardised HTML structure with a uniform appearance for website display and standardised annotations and links for complex searches and queries.

Converting the PDFs into HTML makes them suitable for manual curation. Manual editing is necessary to deliver a high-quality outcome because of author variations in the submission template (e.g., variant headings), diverse text options (e.g., bullet lists, enumerations and tables), and the inclusion of graphs, mathematical formulas, chemical symbols, and images. An automatically generated HTML would rarely be suitable for direct use, but some automatic clean-up procedures were developed (e.g., removal of extra whitespace) to alleviate curation burden.

Many small editorial alterations were required to standardise document structure and ensure the five primary sections of the template were properly separated and labelled. The curation team also collected structured data relating to literature referenced in ICS section (3) *References to the research,* extracting the text of bibliographic references, Document Object Identifiers (DOIs) and year of publication.

To determine the ideal functionality of the database, reference was made to the user-experience (UX)-led design process that supported the development of the UK REF 2014 Impact Case Study database.[2] This had been done to assess how the public website should work and involved interviews with relevant stakeholders such as university research offices, research funders, academics and government departments. These interviews identified functional and non-functional requirements in the contexts of searching, data modelling and presentation.

The functionality of the UGC website is aligned with that of the UK database and the UX website model was relevant to both. Key features included:

- **Faceted browsing** to enable users to browse the data according to indexed criteria such as the submitting institution, Unit of Assessment (UoA), impact sector or location of the impact.
- **Search** of the ICS text using powerful query operators, for example to look for terms near to others, compound phrases, and with wildcard characters.
- **Metadata enhancement** with additional fields created editorially and associated with the ICS, through automated techniques and manual tagging, including geographic entities (locations), research disciplines and linked references via Web of Science UTs and DOIs.

Task B: Data mining and enrichment

The data contained in each ICS needed to be supplemented with additional information extracted from the text using data mining and machine learning techniques, allowing the analysts to identify and group ICS according to additional categorisation schemes as well as linking bibliometric data for cited research.

A major focus for the analysis of ICS text, once converted from PDFs, was topic modelling. This is a language processing technique applied to document sets to understand the different combinations of words or phrases (topics) that are present. Because it is data-driven, results are derived from the data itself and thus not dependent on subjective notions of structure.

Topic modelling proved to be an effective tool in our prior REF 2014 analysis, aiding understanding of the makeup of ICS in terms of beneficiary groups, pathways to impact, and relevant policy issues. Generating topic models on different ICS sub-sections is especially useful as it can yield complementary insights. For example, the text from (1) *Summary of the impact* provides a good impression of the overall domain of impact whereas text from (4) *Details of the impact* surfaces more detailed information relating to beneficiary groups, locations and impact types.

Topic modelling requires the analyst to specify the number of desired topics. Too small a number (e.g., 5-10) leads only to broad and general groupings. As the number is increased (e.g., to 25 or 50), more granular topics appear. When the number is too high then duplicates emerge and artifacts appear (e.g., topics relating to text such as common journal names).

The ICS text also needs to be normalized (i.e., removal of punctuation and diacritic characters) and domain specific stop-words (words used frequently that don't discern documents from one another) need to be removed (including words appearing in > 50% documents). The text of all 342 ICS was then scanned for word frequency, which reflects the overall thrust of the reported work (see word cloud in Figure 1).

[2] impact.ref.ac.uk/casestudies

Figure 1: Word cloud generated from collating frequent terms in 342 Hong Kong universities' Impact Case Studies. This highlights the focus on 'Hong Kong', 'China', 'research', 'impact' and 'work'.

Multiple models were generated and scanned for content to determine a suitable and useful number of topics. This process led to the identification of 35 meaningful topics with a high frequency of shared content and a discernible relationship to other classifications (Figure 2).

The indicative clusters were reviewed and checked independently by several analysts and then reviewed by the UGC secretariat to create a consensus grouping of 11 thematic clusters of topics closely related by content and focus (Figure 3).

Geographic location of ICS impact is an important feature for analysts and policy makers. This is usually described in the ICS text, so standardised indexing of diverse mentions of geographic entities provides additional benefits to database users. Furthermore, users can focus on impact regions if the location of the mention among the five ICS sections identified. Open-source software DBPedia-spotlight were used to mine ICS text for these mentions of locations and, since this is built on top of Wikipedia data, it is able to disambiguate locations given context (i.e., the words surrounding the mention), and can recognise a variety of name-forms for cities, regions and countries.

Geographic locations were linked to ICS using open-source identifiers, such as Wikipedia and Geonames. This will enable analysts easily to reuse the data for mapping and geospatial tasks without the need for additional data licenses.

Document references providing supporting evidence were also listed in each ICS in (3) *References to the research* which contains up to six citations, usually journal articles or books. By linking these to ICS data, additional analysis can be applied via bibliometric analysis. The references were identified and extracted from the text during the curation process. DOIs associated with these references optimised links to bibliographic databases and any references lacking these were run through the Clarivate record matching service to obtain the correct DOI.

Figure 2: Network of distinct topics found among 342 Hong Kong universities' Impact Case Studies. Lines show linkages between these clusters based on the relative frequency of key terms. Closely linked topics (high relative frequency of common terms and phrases) which suggest clusters of cognate research, e.g., 'Energy' and 'Transport Engineering', are indicated by shared colours.

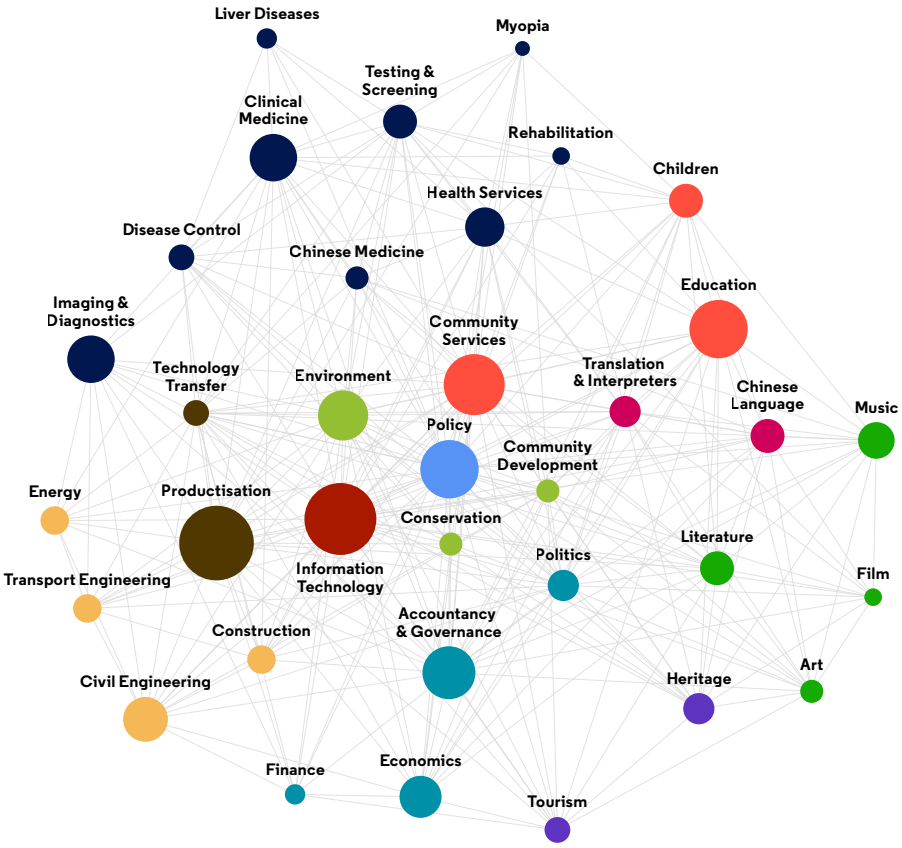
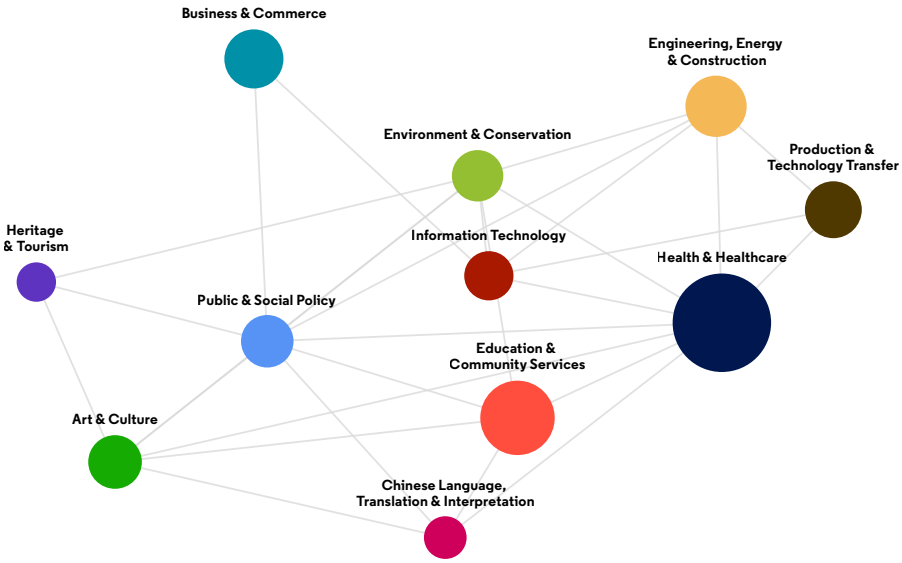


Figure 3: Consensus model of eleven thematic clusters derived from the initial set of 35 subject-based topics. These clusters are the focus of subsequent analysis and reporting.



Research classifications could be taken directly from the UoA to which each ICS had been submitted. However, it is informative to associate each ICS with multiple, granular research classifications, for example to distinguish research in sub disciplines (e.g., organic versus inorganic chemistry) or to help identify interdisciplinary research. To achieve this, Web of Science journal categories (there are 254 subject categories covering all areas of science, social sciences and the humanities, with up to six categories assigned per journal) were identified for each of the linked references to select the most appropriate.

To supplement this, manual assignment was made for cited references to books, reports or other documents not classified in the journal database.

Curated HTML for each ICS were integrated with these additional metadata, generated through topic modelling, geographic entity extraction, DOI linking and research discipline assignment. The combined records were loaded into an appropriate data model. The database can be accessed either through a dedicated website, designed for the purpose to enable users to explore the data interactively.

Task C: Reading, coding and analysing

All the 342 available ICS were read to identify and code features that would allow for cross-case analysis and become the basis of synthesised impact reports based on the 11 thematic clusters identified in Figure 3. The task employed the topic modelling and directed content analysis in a sequential multi-method approach.

The results of the initial, exploratory topic modelling were used to group the ICS for analysis. Grouping by topic at the outset means that ICS were read and analysed in batches that were similar in content and focus, enhancing the coding and analysis and thereby strengthening the impact reports. Qualitative directed content analysis was used to elucidate the central characteristics of the impact narratives within topic clusters. This involved an iterative process of examining ICS and the development of a code book to categorise salient features, allowing patterns between the codes to be described in impact reports.

The codebook was developed using the team's expertise in research impact and underlying processes and refined through discussion with the UGC and a review of existing research impact literature. The code book comprised four main sections: a) aspects of the underpinning research, including the motivations behind research; b) calibration points used to determine the time between the onset of the research and impact; c) the activities and mechanisms of translation from research to impact; and d) characteristics of the impact itself, such as beneficiaries and type of impact. Specifics such as quantifiable impacts (e.g., impacts described in terms of patients treated, or the value of a licensing agreement) were also coded, but, as with the UK REF 2014, it proved impossible to reconcile these figures to any consistent baselines for comparability.

ICS were analysed using Dedoose software following the content analysis approach. This began with importing the HTML files into the program and assigning each ICS to its topic cluster using descriptor variables. The focus moved from primary topics to categorisation and exploration of the content of each ICS narrative, assigning relevant text extracts to the codes and sub codes set out in the code book. This enables understanding of

variability and consistency within and across thematic clusters. Through this process, ICS properties were systematically recorded and evidence for each feature was collated. Code application charts identified thematic intersections between overarching codes (e.g., items associated with particular beneficiaries) as well as ascribed topics.

On reading, a small number of ICS (n=26) seemed to be false positives in the content of the topic models. That is, they were only peripherally related to the data-generated topic. This is not unusual in topic modelling but given the ICS were being read we reallocated these ICS to a more relevant thematic cluster.

Cross-case analysis drew out similarities and differences between 11 ICS clusters (Figure 3). A standard set of visualisations was developed to support reference and reporting materials. These are exhibited in the synthetic analysis that follows.

Codes were not only used for analysis at this stage but also exported and incorporated into the ICS database to facilitate advanced searches. For example, a search can now be conducted on sector of impact (e.g., manufacturing, public administration and education), which is an innovation not feasible for the UK REF 2014: groups could not be identified via automated text mining of several thousand documents but could be consistently tagged by reading and coding each UGC ICS.

A short impact report was generated for each substantive theme to evidence the societal, economic and technological impact of Hong Kong research. Each report is based on the cross-case analysis but written to enhance its role as an accessible information source. Each narrative draws on and cites specific examples of impact, with full representation across the eight UGC-funded universities.

Limitations on analysis and interpretation

The analysis in this report and the thematic report, and interpretations based on that analysis, are based wholly on the evidence, statements and data contained in the 342 ICS submitted by the eight Hong Kong universities, reviewed by the 13 RAE panels, and made available by the UGC. The ICS intentionally contain a wide diversity of claims about research impact, varying in their nature, scope and scale just as does the underpinning research. It is not the task of the analysts to make value judgments about the statements in the ICS nor to validate any particular claim, either quantitatively or qualitatively, after it has been reviewed by the RAE panels but to take this evidence at face value and to develop an accessible report on the work of the universities.

The website and its use

A website has been developed to showcase the RAE 2020 Impact Case Study data. The website presents the original ICS documents alongside enhancements that provide additional metadata relating to impact topics, impact locations, impact sectors, research categories, and funders. All 342 ICS are indexed, allowing users to search for those that mention terms or phrases of interest, or to filter according to metadata fields.

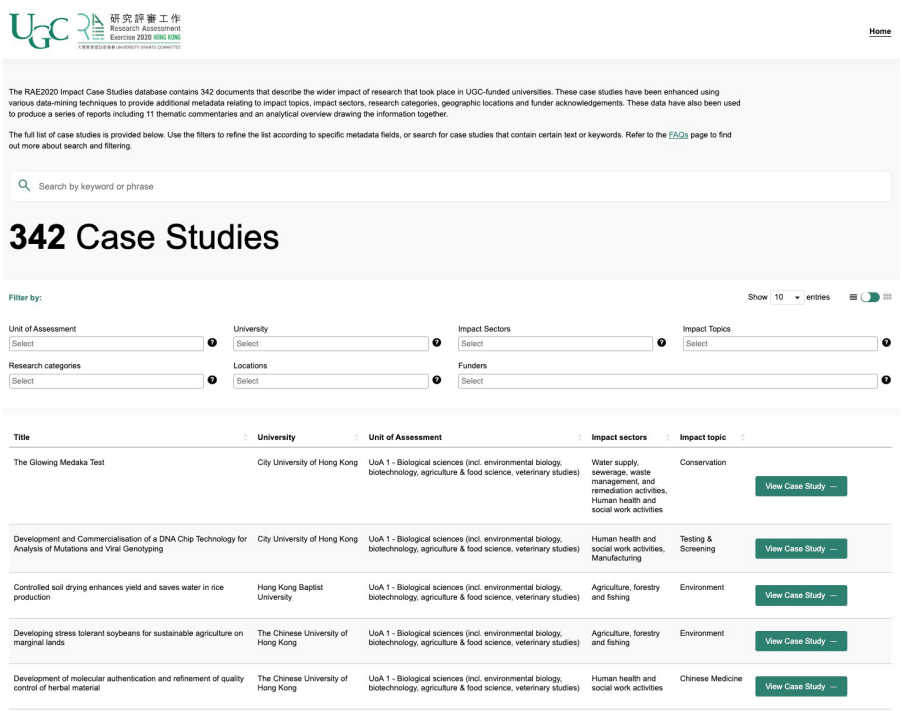
Drawing on our experience with the UX design process used to develop the UK REF 2014 database, we have focussed on providing a simple website that gives users a variety of ways to access the data according to their particular needs. For example, some users will prefer to use established taxonomies (such as classification by Unit of Assessment), whereas others will want to find research relating to a specific concept or location.

Broadly, the website content can be separated into three types which are outlined below:

Homepage Index

The page where users will initially encounter the data is the index of case studies. This page provides a summary list that can be viewed as a table (as shown in Figure 4) or with more detailed cards. By default, the complete list of 342 ICS is displayed. Users may choose to refine the list by using the search box at the top, or by using the filters above the results list.

Figure 4: Screenshot of the homepage index.



Keywords searches are likely to be used to identify certain concepts of interest, such as 'patent', 'climate change', or 'sdg' (UN Sustainable Development Goal). It is also possible to find words that feature near to others, which is often helpful to clarify ambiguous terms such as migration, screen, or environment.

Seven filters are provided (Table 1). A list of possible values is displayed when the user clicks on the filter.

For certain fields (labelled hierarchical), this list is organized in a hierarchy to aid discovery. For any filter, the search box can also be used to find certain entries which may be more appropriate for filters with many options (such as research categories, locations and funders). Some fields may associate ICS with multiple values as indicated in the final column of Table 1. In each case, explanatory text is supplied via a tooltip icon (?).

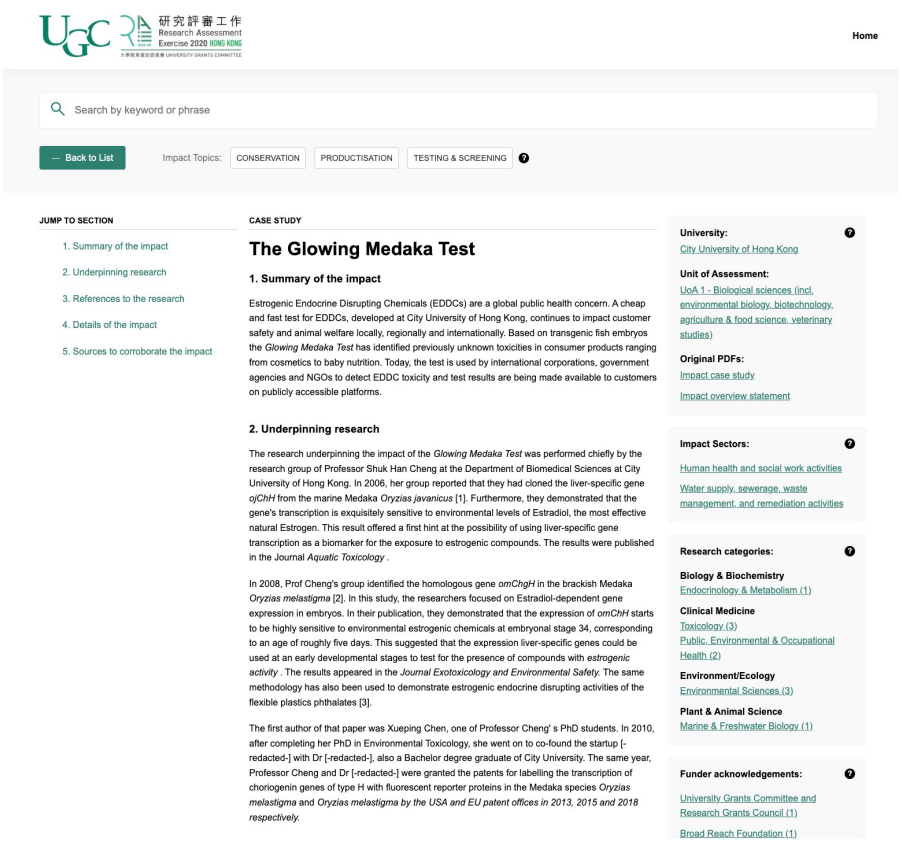
Table 1: Filters available for searching the Impact Case Study database.

Filter Name	Hierarchical	Multiple Values
Unit of Assessment	Yes – UoA under panels	Yes
University		Yes
Impact Sectors		Yes
Impact Topics	Yes – impact topic under thematic clusters	Yes
Research Categories	Yes – research subjects under fields	Yes
Locations	Yes – continents containing regions containing cities / towns	Yes
Funders		Yes

Impact Case Study Pages

Whenever a user clicks "View Case Study" they are taken to a page that displays the ICS document alongside the metadata enhancements (shown in Figure 5). A three-column layout is used: the first column provides an index allowing users to jump to different sections of the ICS; the middle column shows the original ICS document; and the right column displays metadata fields. The values shown for these metadata fields link back to a search result page for that particular entity. This provides users with a rapid means to locate related ICS. In some case, a weight (display in parenthesis) may be associated with the entry. For example, the number next to a location denotes how many mentions were found. Explanatory text for each metadata field is provided using tooltips icon (?).

Figure 5: Screenshot of an Impact Case Study page.



Information Pages

Additional content is provided to assist users in their use and understanding of the database. An extensive FAQ page provides answers to likely questions and gives detailed explanations relating to the methodology used for data enhancements.

Bibliometric analysis

To place the RAE 2020 analysis of impact into a global context, the recent publication output of Hong Kong's research base is reviewed using bibliometric data collated from the Web of Science.

Background

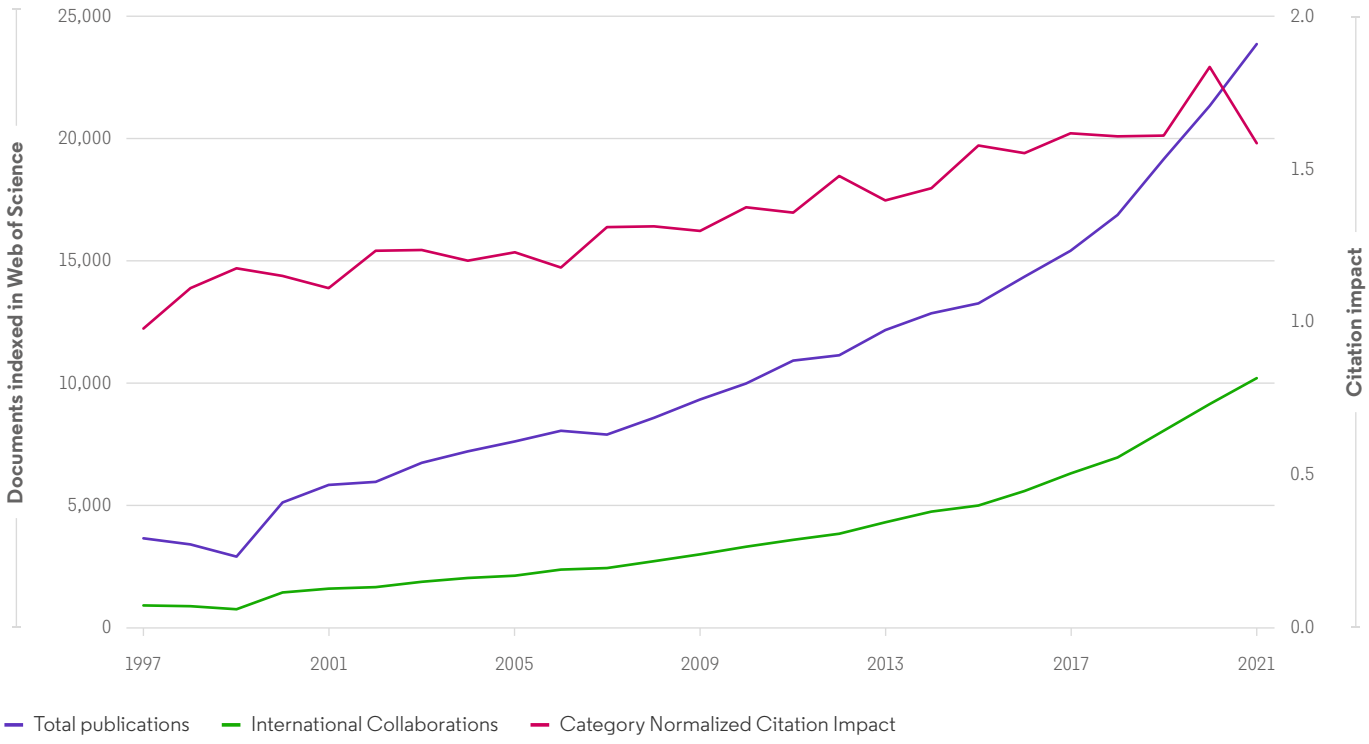
Hong Kong's published research output, in the 20,000 journals indexed in Clarivate Web of Science Core Collection, has risen steadily over the last twenty years from around 5,000 papers (substantive academic articles and reviews) in 2000 to about 25,000 per year recently. International collaboration has risen slightly more rapidly, as has been the case worldwide during the last two decades, increasing from a little less than 30% to more than 40% of total output, as illustrated in Figure 6.

Most published academic papers are authored by researchers at the UGC-funded universities, although the data in Figure 6 include other public sector research institutions and any papers for companies located in Hong Kong. The published output of the individual academic institutions has increased in line with the overall profile and all institutions expanded at broadly the same rate.

Average citation counts are, for reasonably large samples of journal publications, generally recognised as an indicator of academic impact. Citation counts increase over time at a rate that is field dependent (e.g., biosciences cite more frequently than technology) and is also influenced by document type (e.g., reviews are cited more often on average than articles). Current counts are therefore 'normalised' to a common standard for analysis by comparison with the global average for similar documents in journals published in the same year and in that Web of Science category. The citation count for each paper is normalised separately and analyses are applied to the normalised data. No fractional apportionment of citations (e.g., for numbers of collaborating authors) was used for any part of this analysis.

The Category Normalised Citation Impact (CNCI) of Hong Kong's papers has increased from an annual average that was similar to world average (which is 1.0 by definition) to 1.8 times that benchmark in 2020. There was a slight fall in CNCI in 2021 but this may be associated with a similar artefactual dip in the most recent year that has been recorded in Mainland China's papers.[3] Mainland China is a major co-authoring partner.

Figure 6: Annual count and Category Normalized Citation Impact of articles and reviews published in journals indexed in Web of Science and with at least one author or co-author from Hong Kong. Annual publication counts are shown as total and as the numbers with at least one international co-author.



[3] 2018. Adams J. Information and Misinformation in Bibliometric Time-trend Analysis. Journal of Informetrics, 12, 1063-1071. www.doi.org/10.1016/j.joi.2018.08.009

References in Impact Case Studies

It was possible to identify and extract 2,039 references to publications cited within the ICS (note that this is a different dataset to the 16,000 references submitted by the universities for direct assessment by the RAE panels, although there may be overlap between the two).

After cleaning and structuring, these were matched to Web of Science article records using a standard automated matching process. This provided 1,418 matches. A further 44 documents were matched manually after checking and amending errors in references.

This process produced a total of 1,462 validated matches between ICS references and Web of Science records. The publication date was noted for each matched reference in the Web of Science as well as full author information, including the national and institutional affiliations of each author and co-author. It was therefore possible also to analyse the temporal distribution of references and the number of ICS international collaborations and their geographical distribution.

Citation impact of research cited in ICS

There were 16 matched references for which no citation data were available.

Both the average and the median CNCI of the 1,446 with citation data were calculated and it can be seen that, while there is a general correlation between the average and median, there is a more substantial difference for two categories which have an anomalously high average CNCI (Table 2).

The overall average is also far higher than would be expected for a national total. This is a consequence of a general selection of the more highly cited material for inclusion in these case studies and some very highly cited outlier papers: five papers in Health & Healthcare and two papers in Information Technology had a CNCI index that was 100 times greater than the expected average.

Skewed data are typical of bibliometric analyses (many rarely cited papers, a few highly cited) and the median is therefore more informative since it avoids the arithmetic skew. Hong Kong's average CNCI over the period 2016-2020 was 1.65 compared to a world average of 1.0. A number of the median values in Table 2 are close to or above the Hong Kong average and only two (Art & Culture and Chinese Language, Translation and Interpretation) are clearly below. This means that more than half of the referenced papers in the ICS were of above an average citation impact that is itself skewed to the high end of the distribution. We can conclude that the work reported in the ICS is generally based on underpinning research that was of high impact when published.

The relatively low average CNCI for art, humanities and language papers is probably an artefact of two things. First, these are not yet covered in depth in the Web of Science database except for North America and Western Europe. Second, these are subjects which tend to have small citation networks and Asian publications are likely to be less familiar to the western researchers whose work (and hence the citations in that work) is more frequently indexed.

Table 2: Summary statistics for research publication references cited in Impact Case Studies submitted to the Hong Kong Research Assessment Exercise 2020. Data are shown for 11 thematic clusters (Figure 3) and for 1,446 of 1,462 references where citation data were available. The data for each cluster include the count of references from text, the median date of publication during the census period 2000-2019, and the average and median Category Normalized Citation Impact (CNCI). Average CNCI values in **BOLD** are influenced by exceptional outliers (see text).

Thematic Cluster Name	Count of references	Date Median	CNCI Average	CNCI Median
All Impact Case Studies	1,446	2015	**4.45**	1.59
Heritage & Tourism	30	2013	2.21	1.33
Art & Culture	52	2015	1.01	0.64
Chinese Language, Translation & Interpretation	22	2015	1.45	1.14
Education & Community Services	186	2014	2.54	1.08
Business & Commerce	133	2016	3.41	1.96
Public & Social Policy	65	2015	3.10	1.64
Health & Healthcare	413	2015	**7.16**	1.90
Environment & Conservation	130	2013	3.70	2.21
Information Technology	94	2015	**8.49**	1.83
Engineering, Energy & Construction	189	2014	3.32	1.62
Production & Technology Transfer	131	2014	2.25	1.59

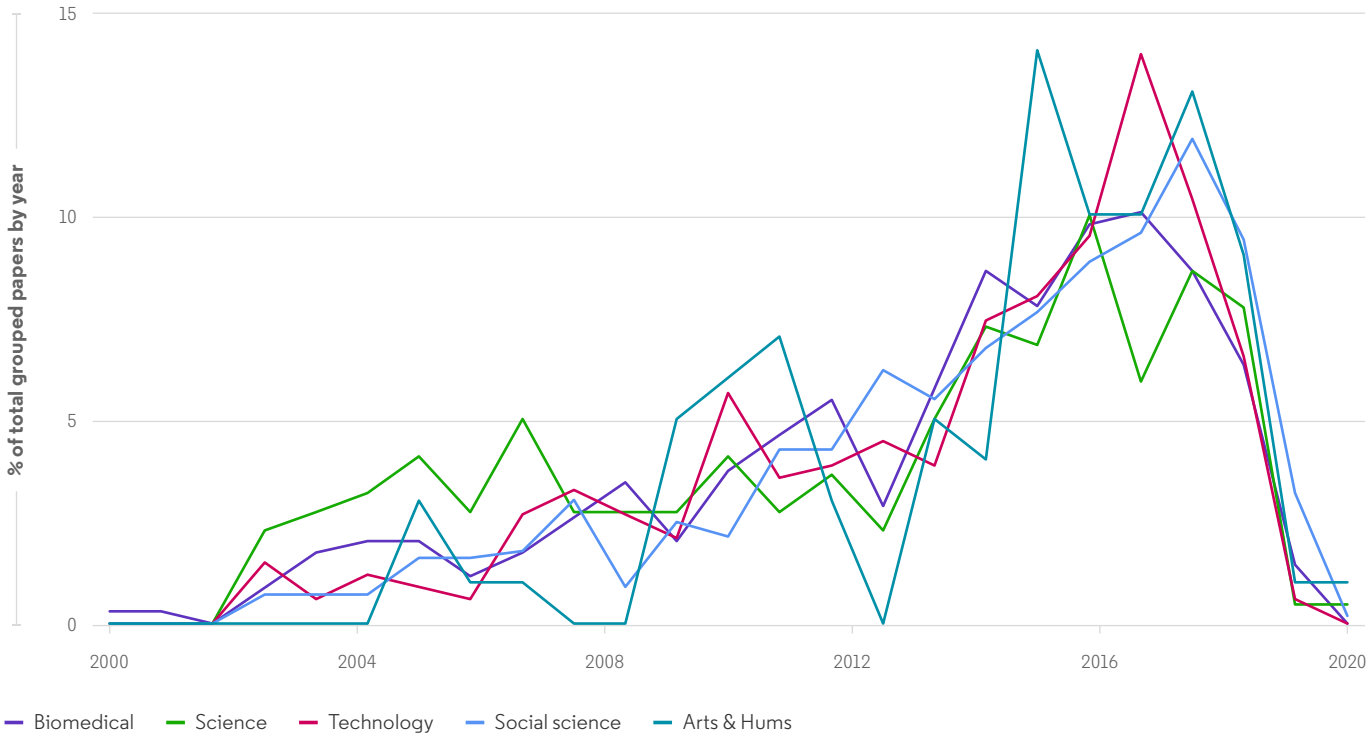
Date of publication of underpinning research

The overall median date for these publications was 2015. The median publication date varied between thematic clusters, but not to any marked degree.

For easier visualisation of the time profile of references, which tend to be relatively few per year for the earlier years, the clusters have been organised into five 'faculty level' groups and the overall time profile of these groups is shown in Figure 7.

Because of the different numbers of references in each cluster (Table 2) the annual counts have been calculated as a percentage of the total for each group, so as to provide some comparability between 'faculties'. The differences are not marked but the data suggest that science-based subjects tended to draw on earlier references. The peak phase for references in the ICS was relatively recent (2014-2020) for all subject areas, perhaps reflecting in part the RAE 2020 requirement that underpinning research had to occur between 2000 and 2019.

Figure 7: The publication dates of references cited in Impact Case Studies submitted to the Hong Kong Research Assessment Exercise 2020. Data are collated into five broad 'faculty' groups from 11 topical clusters and shown by year as the percentage of total references per group.



Collaboration

More than half of the matched documents (794 of 1,462 = 54%) had international co-authors; there were 1,601 non-Hong Kong address affiliations, because of multinational co-authorships; and some 66 regions co-authored at least one of the references. This is a greater proportion of international collaboration than is typical for Hong Kong's publication portfolio (Figure 6): the percentage of Hong Kong's papers indexed in Web of Science that are internationally collaborative increased to slightly more than 40% in each of the five years to 2021.

The most frequent collaborating region was Mainland China, which co-authored 27% of the papers and this may reflect multiple affiliations for postgraduate students. Mainland China has been an increasingly frequent research partner for Hong Kong in the last decade. Five regions appeared as co-authors on 50 or more references. The 20 most frequent co-authoring regions accounted for 95% of all collaborations and, with the exception of the USA and Canada, were from Asia-Pacific or from Europe. This broadly reflects Hong Kong's normal pattern of international partnerships except that the relative numbers of Asia-Pacific papers included as references was slightly more frequent and some leading EU co-authors, such as Germany, were relatively less frequent (Table 3). This may indicate the balance of regional impact arising from Hong Kong's research.

The spread of references varies by subject area, partly because of the numbers of case studies and partly because references are used more frequently as evidence in some disciplines. A summary of these data, focussing on the partner regions with at least ten co-authored references, shows that the numbers of references per ICS was least in the arts-based clusters (2.5 or less in heritage, arts social policy) and higher in the technology-based clusters (4 or more in health, environment, IT, engineering and production). The numbers of co-authoring regions per ICS was less variable (between 0.5 and 1 partner region), perhaps reflecting rising geographic diversity within larger topic clusters.

Table 3: International co-authored academic papers referenced in Impact Case Studies submitted to the Hong Kong Research Assessment Exercise 2020. Data are shown for the five most frequently collaborating regions and then for the next 15 grouped by region. The number of submitted references is compared with the total co papers -authored between Hong Kong and that region during the assessment period.

Region	ICS references	Web of Science 1997-2021
Hong Kong	1,462	101,293
Mainland China	392	35,299
USA	266	42,081
UK	111	17,845
Australia	70	16,147
Canada	59	10,445
Singapore	44	8,614
Japan	31	7,251
Taiwan, China	29	7,071
South Korea	28	5,156
Malaysia	12	2,378
New Zealand	12	2,166
India	9	3,264
Thailand	9	2,147
Germany	25	7,524
Netherlands	24	4,470
France	20	5,529
Switzerland	17	3,294
Spain	12	3,602
Denmark	9	2,549
Italy	9	4,410

There is a contrast in partner frequency between economic/social clusters and science/technology clusters. Mainland China is an increasingly dominant centre of research in science and technology and it is therefore unsurprising that Hong Kong finds many excellent partners for research supporting its impactful research among Mainland universities.

However, Mainland China has historically invested less in its social science disciplines, although this is now an expanding area with rising academic impact. In areas like education, commerce and public policy, it is the USA which is the most frequent co-author with other western countries also well represented.

Health & Healthcare is the largest cluster by ICS count (64). It also has the greatest abundance of references per ICS (6.5) and the greatest number of international partners (43), although it is Education & Community Services (with 40 partners across 44 ICS) that has the greater frequency (0.89 per ICS cf. 0.67 in Health). (Table 4)

Table 4: Frequency by thematic cluster of international co-authorship on academic papers referenced in ICS submitted to the Hong Kong RAE 2020, for the regions with 10 or more co-authorships. For each cluster, the table also shows the number of ICS that were submitted, the total count of references and the total number of co-authoring regions (some references will be co-authored by several regions).

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
Case studies	12	24	17	44	35	31	64	25	24	36	30
Total references	31	54	24	189	133	69	416	130	95	190	131
Co-author regions	14	8	1	40	23	14	43	29	13	26	10
Mainland China	1	6		19	25	9	128	50	41	60	53
USA	6	8		33	44	18	89	20	16	20	12
UK	6			14	10	5	45	8	4	18	3
Australia	5			16	8		24	4	4	9	
Canada	4			8	7	1	23	6	1	8	1
Singapore	1			5	12	6	10	1	6	1	2
Japan		1			2		12	9	2	4	1
Taiwan, China	1			5	2		14	1	1	4	1
South Korea				1	1	2	13	6	1	4	
Germany	1	1		3	1		11	3	1	2	2
Netherlands	2	2		1	5	1	9	3			1
France	1	1		2	3	1	8	3	1		
Switzerland	1				1	3	8		1	2	1

Major themes and key questions arising from the analysis of the ICS

This section summarises the findings in the eleven thematic reports, which should be consulted for detail on particular ICS and the broad range of work developed in individual universities.

The analyses that follow in this section broadly follow the flow of research and development: motivation; key stakeholders; funding sources; types of impact; pathways of translation from research to impact; the time-lag between research origin and impact; the location of impact; and identification of those who benefit from research impact.

The distribution of numbers needs some interpretation because each thematic cluster contains a different number of ICS, from 12 in Heritage & Tourism to 64 in Health & Healthcare. Comparing activity and outcomes directly across themes is therefore not always wholly informative. These numbers should be borne in mind when reading the report as explained in the text box.

It must be understood that the different nature of research cultures and objectives in the humanities, in the natural sciences and in technology disciplines lends itself naturally to different kinds of outcome and thus differences both in the types of impact and their likely beneficiaries. Nonetheless, the evidence points to many opportunities for very broad crossovers and 'impact' itself is naturally interdisciplinary. Science and technology are more likely to lead to outcomes that engage with industry, but art and design will contribute (sometimes critically) to product design. The humanities and social sciences frequently point to societal outcomes but these may be mediated through improved technology or via changes in human environment. The economy thus benefits from research developments in many areas and through many routes.

How the data are presented

The numbers of ICS vary between themes and the numbers of coded events or links vary between ICS. Because of these differences, analyses may be expressed as 'counts', 'mentions' and 'instances' and as values or percentages (as relative significance in graphs) within themes in the following sections.

Each table notes the distinction between: 'count' (the number of ICS in a theme and the denominator used when expressing percentages in the figures); 'mentions' (the number of times a particular code is used for a particular topic eg motivation); and 'instances' (the number of case studies in which a particular code is used for a particular topic). This addresses the fact that an ICS could be coded multiple times for a particular topic.

Care should be taken in interpreting high percentage values that are reported for activity in the smaller clusters where the numbers are in fact low.

How complex is the research landscape?

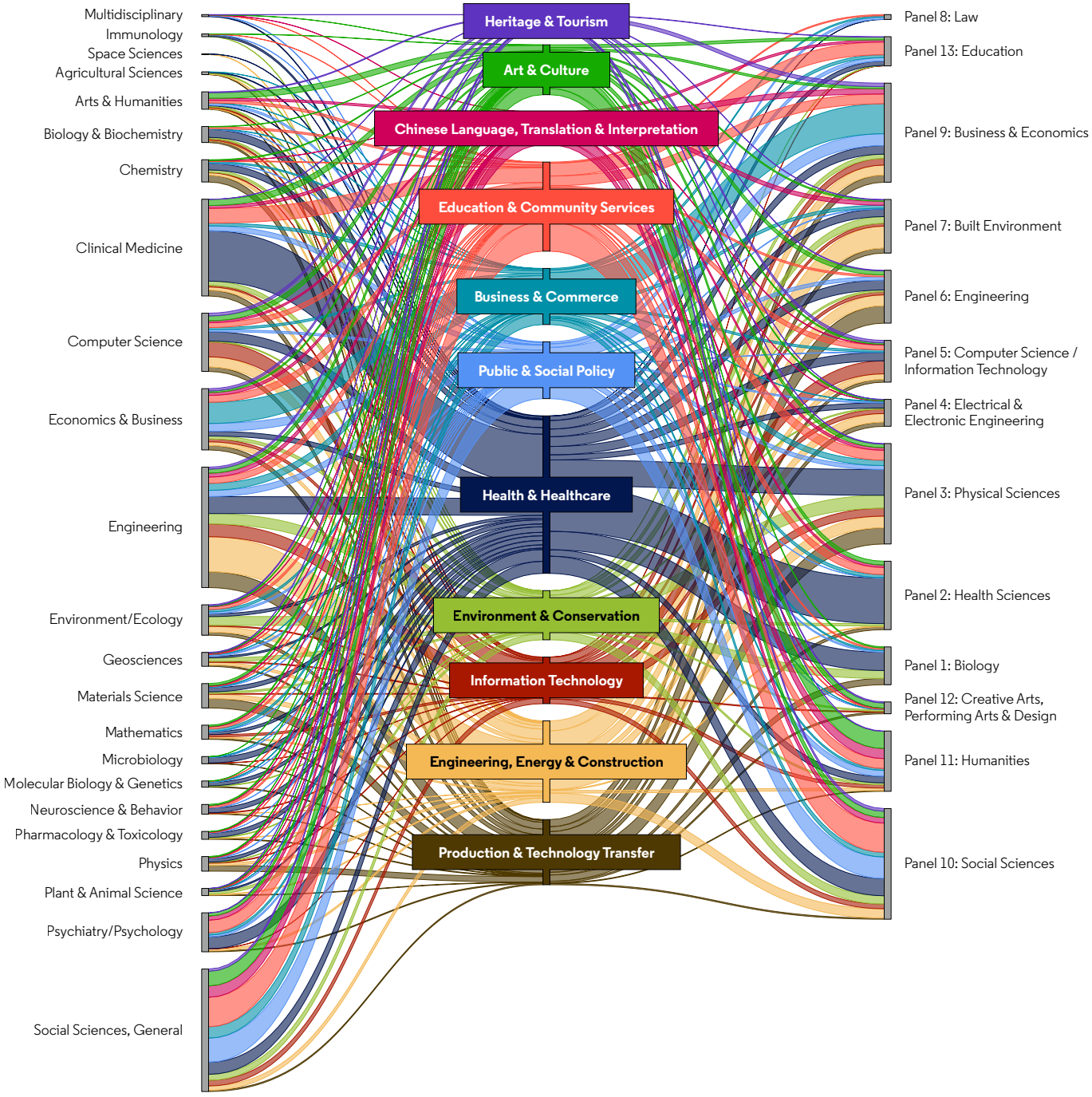
Each cluster in Figure 3 draws on a spectrum of ICS that were reviewed by several different RAE panels in RAE 2020. The impact wheels that open each of the eleven thematic reports evidence the spread of relevant research and impact; for example, Education & Community Services links to no fewer than 18 UoAs whilst the Business & Commerce cluster is concentrated across four UoAs.

Analysis of the references in each ICS confirms that each cluster contains impact stories supported by a diversity of original research drawn from many academic disciplines: for example, the Art & Culture cluster links to both mathematics and engineering.

This complex landscape demonstrates the way in which original academic disciplinary research leads to cross-disciplinary innovation, which in turn has a swathe of possible impact outcomes that are later realized across the economy and society. This complexity shows why it is difficult to predict where research will have an impact and, as reviewed in a later section, how long the gap may be between research and impact.

The flows between disciplines, impact clusters and the ICS seen by individual review panels is shown in Figure 8. This confirms a key finding in earlier work on the UK REF2014 ICS, that "the underpinning research within [subject areas] is multidisciplinary in its own right".

Figure 8: Alluvial flow diagram showing connections: on the left, between research disciplines and topical clusters of Impact Case Studies (connected by references cited in the case studies); and, on the right, between topical clusters and the Hong Kong RAE subject panels that reviewed the ICS submitted by the universities. Colour bands are determined by the topic cluster (see Figure 3).



What is the motivation for research?

Research may be motivated by both internal pressures (push factors) and external demands (pull factors). Fundamental, curiosity-driven research is typically driven by the push factor, seeking to extend an existing line of enquiry and to answer new questions thrown up by previous work. Applied research may come from the recognition that a discovery offers a solution to known constraints or from the pull factor of identified needs and limitations expressed by companies or through public policy priorities.

The motivations described by the Hong Kong ICS contain a relatively even balance of push and pull factors, with a slightly greater tilt towards push factors in Healthcare and IT and towards pull factors in Engineering (commissioned research) and Production (to improve technology) as illustrated in Table 5 and Figure 9.

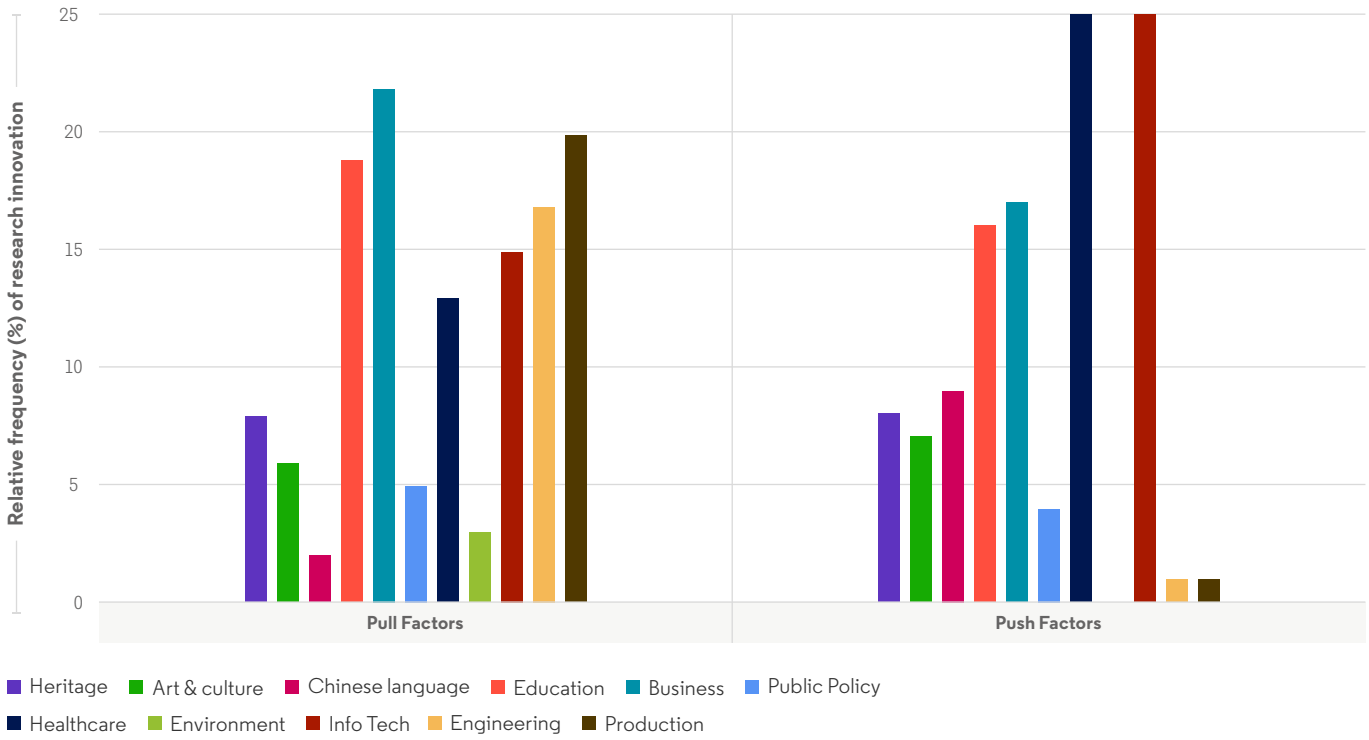
It is interesting to note that although further research development was an identifiable factor in Health & Healthcare, neither push nor pull factors were strongly identified relative to the numbers of ICS in the core sciences (Health, Environment) or in Education. Nonetheless, these are research areas that have a direct and significant impact on both society and the quality of life and it might reasonably be inferred that factors requiring 'further research development' were implicitly addressing those societal goals. The impact analysis supports this hypothesis.

Table 5: The frequency with which motivation factors were identified in Impact Case Studies.

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
ICS count	12	24	17	44	35	31	64	25	24	36	30
Total mentions	16	13	11	35	39	9	38	3	40	18	21
Instances of Pull Factors	**6**	**5**	**2**	**17**	**19**	**5**	**12**	**3**	**11**	**14**	**16**
Commissioned	4	5	0	10	7	5	3	3	4	11	3
Improve technology	1	0	0	0	3	0	5	0	9	5	15
Better protocols	2	1	2	7	10	0	4	0	0	1	1
Barriers to take up	0	0	0	2	1	0	0	0	0	0	0
Test best practice	1	0	0	0	1	0	1	0	2	0	1
Instances of Push Factors	**7**	**6**	**9**	**15**	**15**	**4**	**24**	**0**	**16**	**1**	**1**
Advances creating new questions	0	0	0	2	3	1	8	0	7	1	0
Advances enabling new research	1	0	0	1	0	1	2	0	2	0	0
Follow on from previous research	3	3	2	6	10	0	8	0	9	0	1
Investigator initiated	4	4	7	7	4	2	7	0	7	0	0

'Total mentions' is the number of times this category (here 'motivation of research') is coded within the 11 themes. This is the total of the subcodes in each panel of the table (here 'Commissioned', 'Advances creating new questions', ... etc); the 'Instances' (of push and pull factors) provides a summary of the number of mentions across the subcodes (thus avoiding double counting) and is also presented in Figure 9 as a percentage of all number of case studies (ICS count).

Figure 9: The relative frequency with which Impact Case Studies in 11 thematic clusters identified a 'push' or a 'pull' factor in motivating research. Numbers are shown as a percentage of the total factors of that type.



Commissioned research was significant in Heritage & Tourism (cited in 33% of ICS, i.e., 4/12), Engineering, Energy & Construction (31%) and Education & Community Services (23%), along with – in line with expectations – Business & Commerce (20%) and Information Technology (17%).

The demand for research that would underpin better protocols, practices and policies proved an important factor in Business & Commerce (29%), Heritage & Tourism (17%), Education & Community Services (16%), and for Chinese Language, Translation & Interpretation (12%).

The explanation of the latter is the need for properly informed medical interpretation in healthcare.

For example, The Chinese University of Hong Kong and Hong Kong Baptist University were founding research institutes for the Hong Kong Chinese Materia Medica Standards (HKCMMS). The natural ingredients on which Chinese medicines is based can appear confusingly similar. As a result, some consumers have been poisoned due to mistaken herbal drug identities. This project has increased awareness across the Chinese medicine sector, evidenced by a significant decrease in the cases of poisoning.

User demand for better innovation and technology was less frequently cited as a factor in Health & Healthcare (8%) than might be expected whereas this featured in many more Production & Technology Transfer ICS (50%).

This was also a lead factor in Information Technology (38%) where research driven by external advances creating new questions was also a frequent motivator (29%). Investigator curiosity research were important in Chinese Language, Translation & Interpretation (41%), Heritage & Tourism (33%) and Information Technology (29%). Research that followed on from previous work were also important for Information Technology (38%) along with Business & Commerce (29%) and Heritage & Tourism (25%).

What are the sources of research funding?

Analysis of the underpinning research references showed that there were 2,711 acknowledgments of sources of research funding amongst the 342 Impact Case Studies. Many of these identified funding from the UGC or institutional support, which is ultimately sourced from the UGC block grant. However, there were more than 1,100 other unique funder names. Many of these can be grouped under parent organisations, such as the various parts of the US National Institutes of Health (NIH) which is a global supporter of health research.

The list of most frequently acknowledged organizations is clearly dominated by local and regional funding from Hong Kong and Mainland China. The principal US research funders (NSF and NIH) also support collaborative projects as does the European Commission and the UK Research Councils.

In a later section, on organizations informed by research outcomes, the evidence shows the high frequency of private sector partners.

This is also a critical source of information about research needs. However, the needs and benefits are spread across many individual companies and therefore no single business brand appears frequently in this table, but that does not reduce their importance as research drivers.

The diffuse spread of income across multiple sources is also true for the voluntary and charitable sector. About one-third of the ICS in Heritage & Tourism were commissioned and an important source in this context is philanthropy. An example is the Hong Kong and South China Historical Research Programme (HKSCHRP) at Lingnan University benefitted from a donation of HK$14.83m (c US$ 1.9m) from The Hong Kong Jockey Club Charities to create a three-year "Jockey Club Hong Kong History Learning Programme". The Lingnan University team worked with about 60 primary and secondary schools to implement teaching and learning activities which introduced the full breadth and richness of Hong Kong history.

Table 6: Organizations most frequently acknowledged as funding research underpinning Impact Case Studies. Neither the University Grants Committee (and its constituent organizations) nor individual universities are included in this table as they are deemed likely to have contributed to most of the research.

Research funder	Count of acknowledgments
National Natural Science Foundation of China	161
United States Department of Health & Human Services	59
National Institutes of Health USA	58
Hong Kong Innovation and Technology Fund (ITF)	53
National Basic Research Program of China	45
Science, Technology and Innovation Commission of Shenzhen Municipality	34
National Science Foundation USA	20
European Commission	18
UK Research & Innovation (UKRI)	15

What are the types of research impact?

The thematic reports describe a great diversity of impacts across the research spectrum and within thematic areas.

It is important to consider how a research 'impact' may be recognized. Researchers can identify the size and scope of a beneficiary group in some instances, for example by quoting numbers of children attending an education program or the numbers of patients receiving a drug. This gives scale but does not describe the actual impact, which is likely to be reflected in change in a process, or a policy, or in revenue. For this report, we draw on previous work by Williams on types of impact which were classified across four main heads deconstructed in turn into more detailed areas.[4]

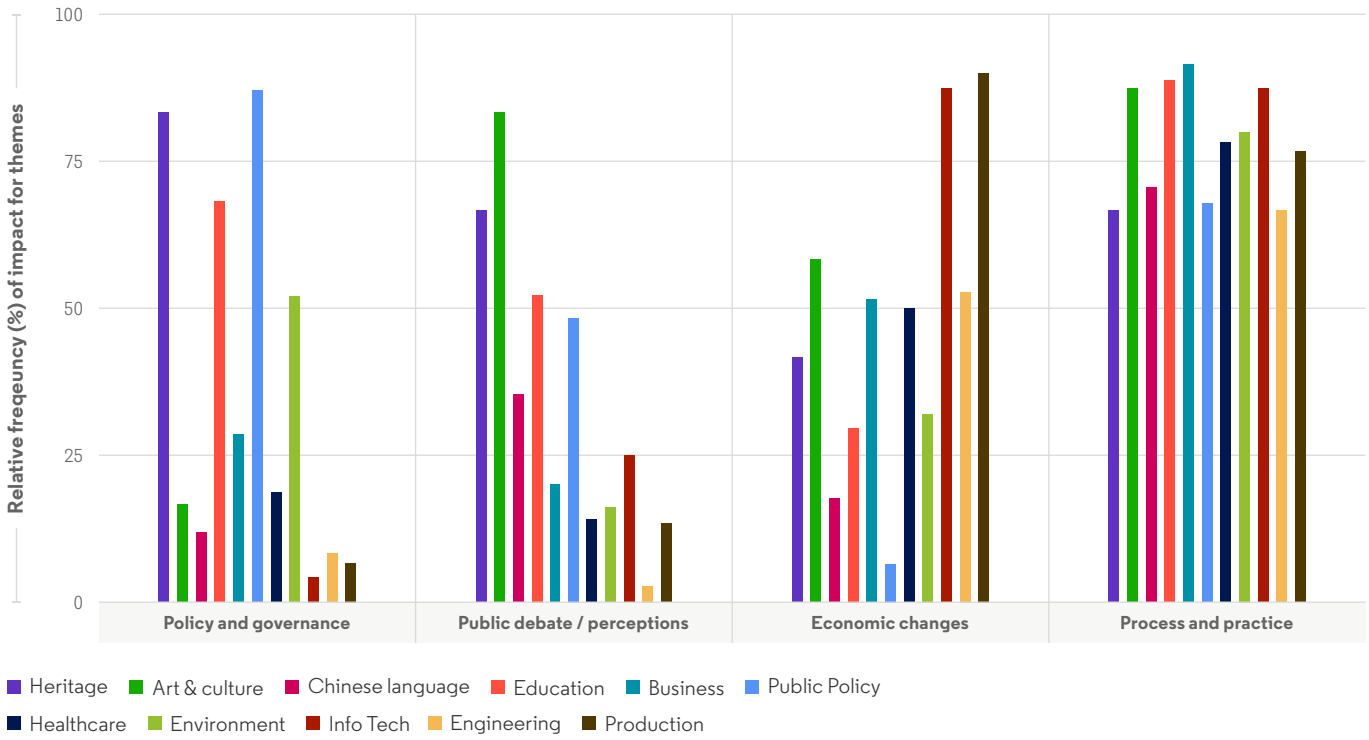
Table 7: The frequency that an overarching impact type was recorded within each of the eleven thematic areas covered by the Impact Case Studies. A full table is in Annex 3.

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
ICS count	12	24	17	44	35	31	64	25	24	36	30
Total mentions	39	86	29	182	140	87	195	63	110	82	185
Instances where the following type of impact are mentioned:											
Policy and governance	10	4	2	30	10	27	12	13	1	3	2
Public debate /perceptions	8	20	6	23	7	15	9	4	6	1	4
Economic changes	5	14	3	13	18	2	32	8	21	19	27
Process and practice	8	21	12	39	32	21	50	20	21	24	23

'Total mentions' is the number of times this category (here 'impact type') is coded within the 11 themes. This is the total of the subcodes in each panel of the table in Annex 3 (for example 'inform public policy'); the 'Instances' provides a summary of the number of mentions across the subcodes (thus avoiding double counting) and is also presented in Figure 10 as a percentage of all number of case studies (ICS count).

[4] 2020. Williams, K. Playing the Fields: Theorizing Research Impact and its Assessment. Research Evaluation, 29(2), 191-202. www.doi.org/10.1093/reseval/rvaa001.

Figure 10: The relative frequency with which Impact Case Studies in 11 thematic clusters identified a change effect in one of four overarching impact types. Numbers are shown as a percentage of the total impacts of that type recorded for each theme.



More than one type of change may be effected by any one piece of research. Social sciences contributed particularly to impacts that effected change in policy and governance while public debate and changed perceptions were influenced primarily by research in the arts and humanities, education and social policy. Science and technology contributed to economic change through innovative research and its development via licences, companies and products. Changes to processes and practice were influenced by the most widespread range of research. (Figure 10)

A direct and quantifiable example of change is the impact of work by The University of Hong Kong. Chronic hepatitis B infection affects 257 million people and causes 880,000 liver-related deaths annually and the standard treatment (lamivudine) was prone to a high level of viral resistance in patients over time. The research team investigated and tested an alternative drug, entecavir, and showed that it was superior in effectiveness and lower rates of resistance. Today, entecavir is recommended for the treatment of hepatitis B in clinical guidelines globally and was added to the WHO essential list of medicines in 2015.

As detailed in Annex 3, researchers recognise the impact of Art & Culture as being mediated particularly through change in public attitudes, behaviour, or knowledge (cited in 83% of ICS ie 20/24), change in practitioners' attitudes, behaviours or knowledge (75%), standard services or products (42%) and enabling innovation in the sector (33%). This is quite different to Chinese Language, Translation & Interpretation where the most frequently cited impact type was informing procedures, practices and protocols (59%), change in public attitudes, behaviours or

knowledge (35%), and change to practitioners' attitudes, behaviours or knowledge (18%). These outcomes are a reflection of the key role that improved interpretation work has had in medicine and health. The frequent citing of practitioners' attitudes, behaviours, or knowledge by Education & Community Services (59%) is much more expected.

In Business & Commerce, research impacts were seen in changes to practitioners' attitudes, behaviours, or knowledge (74%), informing procedure, practice or protocol (57%) and informing guidelines or strategy (51%). This has not all been through the expected route of business management. One example was Hong Kong Baptist University and its impact on the corporate governance practices and policies of regulators, policy makers, and the business sector in Hong Kong and Mainland China. This research raised best practice standards and has been incorporated into professional associations educational materials for seminars on corporate governance. Another ICS at Hong Kong Baptist University aided financial institutions in incorporating corporate social responsibility research practices into credit quality assessment and decision-making boosting competitiveness among exporting businesses in the Greater Bay Area.

Informing procedure, practice, or protocol was a frequent impact cited for social and natural sciences and technology: Public & Social Policy (55% of ICS), Health & Healthcare (64%, clearly related to a frequent motivation for research in this cluster), Environment & Conservation (72%), Engineering, Energy & Construction (39%) and IT (71%).

Impact achieved through change within public sector systems was identified particularly by three clusters informing government policy (Education & Community Services, 57%; Public & Social Policy, 55%; Environment & Conservation, 24%), advancing policy debate (Public & Social Policy, 48%; Environment & Conservation, 36%) and changing public attitudes, behaviours or knowledge (Education & Community Services, 52%; Public & Social Policy, 48%). This is taken into more explicit change through informing guidelines or strategy in Health & Healthcare (41%) and Engineering, Energy & Construction (22%).

In technology clusters there were more specific examples of changes affecting commercial and industrial systems such as improvements to workflows, cited by Information Technology (54%), Production & Technology Transfer (40%) and Engineering, Energy & Construction (25%). Another expected outcome is change in a service or product in regular use (Information Technology, 75%; Production & Technology Transfer, 60%) suggesting a high degree of application and commercialisation. It is intriguing that this also appears in 57% of Education & Community Services ICS, suggesting rapid translation of new protocols in service. Production & Technology Transfer cited change through commercialisation of new technology (70%) and generating profit or revenue (70%), the latter also cited by Information Technology (38%).

What mechanisms translate research into impact?

Table 8 and Figure 11 summarise the main routes by which research is translated into change through mechanisms and through partnerships, with developers and users.

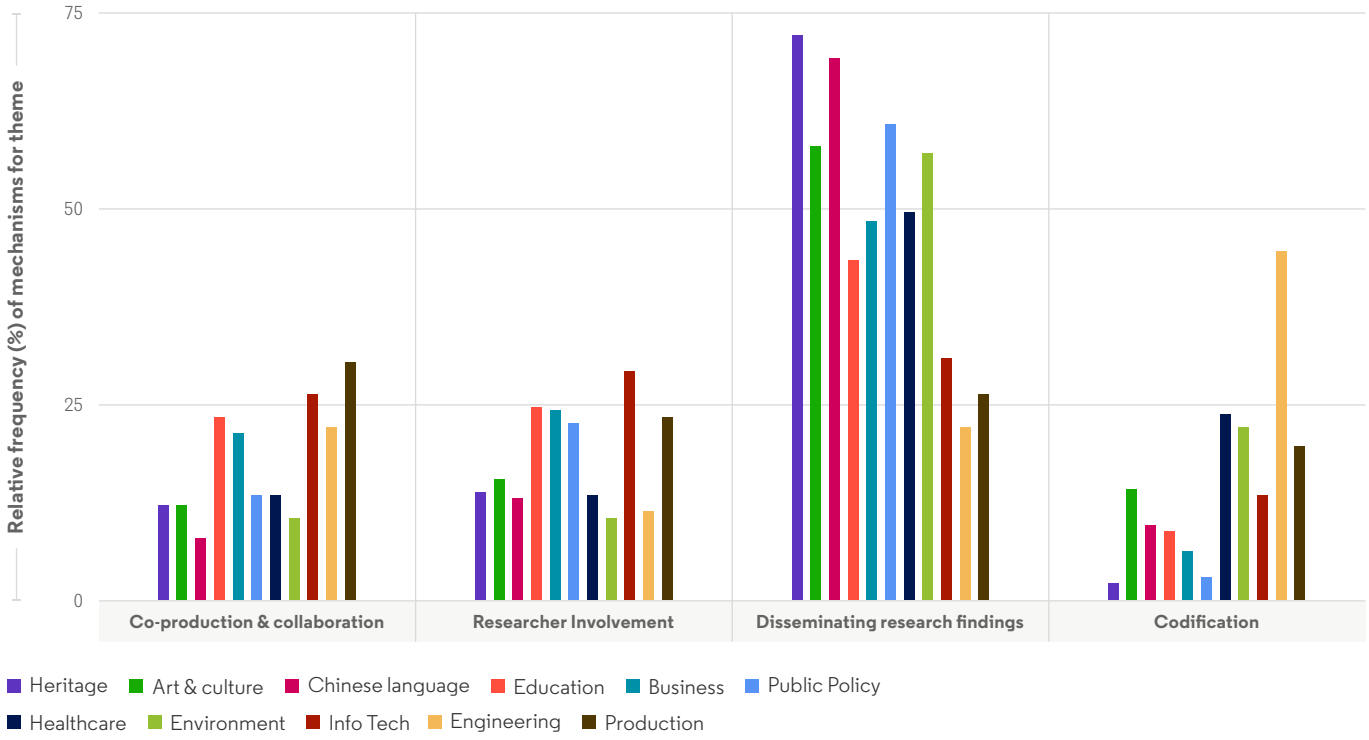
Annex 3 provides details underpinning headings. Note that these routes are not mutually exclusive since researchers may remain directly involved with collaborative partners and that partner may well have been a sponsor of the particular research opportunity from the outset. However, partners are not always required where the research group is disseminating its work through exhibitions, social media, and both formal reports and academic publications. The codification of research outcomes is another significant signal of value recognition and may come in the academic form of prizes and awards or the more economic form of patents and licences, and investment from partners.

Table 8: Mechanisms cited by researchers in Impact Case Studies for RAE 2020 that enabled research to be translated into impact.

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
ICS count	12	24	17	44	35	31	64	25	24	36	30
Total mentions	50	141	62	279	207	97	181	77	126	81	111
Instances where the following type of impact are mentioned:											
Co-production/ collaboration	3	11	5	31	21	7	21	6	15	14	20
Researcher involvement	7	14	7	37	30	18	18	8	17	8	19
Disseminating findings	11	23	17	42	33	30	44	21	17	13	18
Codification	1	15	6	21	11	3	31	11	14	22	19

'Total mentions' is the number of times this category (here 'mechanism') is coded within the 11 themes. This is the total of the subcodes in each panel of the table in Annex 3 (for example 'media coverage'); the 'Instances' provides a summary of the number of mentions across the subcodes (thus avoiding double counting) and is also presented in Figure 10 as a percentage of all number of case studies (ICS count).

Figure 11: The relative frequency with which Impact Case Studies in 11 thematic clusters identified a particular route to disseminating the outcomes of research. Numbers are shown as a percentage of the total mechanism of that type recorded for each theme.



The details underpinning these headings are provided in a supplementary table in Annex 3. This illustrates that media coverage is a primary route for research dissemination for Heritage & Tourism (83% of ICS cited this i.e., 10/12), Art & Culture (79%), Chinese Language, Translation & Interpretation (59%) and Education & Community Services (52%). These research areas will clearly engage with popular and social culture but it is intriguing to find that Business & Commerce and Public & Social Policy ICS also cited media coverage as a primary dissemination route (57% and 68% respectively).

Direct involvement is critical in Art & Culture where the researcher was involved in impact through collaboration with sector (46%) or as an expert, practitioner, or advisor (29%). Frequently, research findings were disseminated through non-academic presentations (71%)

The development of educational and training materials is a well-recognized route for research findings be disseminated both to users, who adopt the materials to improve their own work, and to beneficiaries, for whom this may represent an improvement in the quality of life. It was the most frequently cited path for Chinese Language, Translation & Interpretation (76%) and was valuable for Education & Community Services (66%) and Heritage & Tourism (50%). In Health & Healthcare (36%) this typically represents professional training materials, impacting clinical practice while in Environment & Conservation (44%) it is professional training materials.

An example is work by The University of Hong Kong's Department of Physics on light pollution. Its 2007 survey of light pollution used a citizen-science approach to read the night sky develop a pollution map, leading to the 2011 Hong Kong Government Task Force on External Lighting, and now the project materials enable the topic to be added to the school curriculum.

While media and training materials are important routes for general dissemination to groups, innovative research outcomes are rarely transferred effectively to specialist users in a published form and the continuing involvement of the researcher is frequently essential. Indeed, the reciprocal engagement of the user during the research significantly enhances understanding. Researchers mediating impact through being involved as an expert or advisor were cited frequently social science research such as Business & Commerce (63%), Public & Social Policy (45%) and Education & Community Services (43%). However, this was a less frequent route in scientific research such as Environment & Conservation (24%), Health & Healthcare (20%) and Engineering, Energy & Construction (17%).

The contrast is also seen in Information Technology where direct and on-going involvement is practical rather than advisory, via collaboration in academic and industry partnerships (46%) and co-production of new technology or products (38%). Information Technology also cited open-source data websites and databases (38%) as a unique dissemination route. For example, City University of Hong Kong developed software to combat online surveillance that was downloaded 1.3 million times. Similarly, co-production through academic and industry partnerships was important for Production & Technology Transfer (60%)

The importance attached to formal recognition highlighting the significance of research outcomes, at least by the researchers, is reflected in the frequency of mentions. Prizes and awards were identified by: Production & Technology Transfer (60%), Information Technology (54%), Art & Culture (50%), Environment & Conservation and Engineering, Energy & Construction (both 44%), Chinese Language, Translation & Interpretation (35%), Education & Community Services (27%) and Health & Healthcare (25%). Formal recognition by a professional body was cited by Education & Community Services (27%) while patents were identified by Health & Healthcare (33%), Engineering, Energy & Construction (28%) as well as Environment & Conservation (16%).

Which stakeholders mediate the benefit of research?

Not all impact benefits are tangible. Many stakeholders will receive a benefit from research outcomes not because it directly delivers profit or reduces costs but because it informs or enables decision making.

Benefit therefore comes from engagement with these stakeholder groups, which may or may not be directly involved in the research. Those key decision-takers then disseminate the benefits as new or enhanced products and services. Three major groups of external stakeholders were identified within the ICS as having had an identifiable role in mediating this decision-making.

Table 9: Decision takers: stakeholders that mediated research outcomes into impact.

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
ICS count	12	24	17	44	35	31	64	25	24	36	30
Total mentions	14	15	1	46	68	47	72	22	32	17	29
Private sector	0	3	0	4	26	3	16	4	15	10	20
Government departments/agencies	8	4	0	20	12	17	22	7	7	4	5
NGOs/third sector	0	3	1	12	9	7	15	4	5	2	1
Think tanks	1	0	0	0	1	6	0	1	1	0	1
Politicians	1	1	0	5	2	4	0	1	1	0	0
Political decisions makers	1	0	0	1	4	6	6	4	0	0	0
Professional assoc & trade bodies	0	0	0	1	7	3	2	1	0	0	1
Regulators	0	0	0	0	5	1	11	0	0	1	1
Other	3	4	0	3	2	0	0	0	3	0	0

'Total mentions' is the number of times this category (here 'stakeholder') is coded within the 11 themes. This is the total of the subcodes in the table.

The private sector, including commerce and industry was the largest single group, followed by government departments and non-governmental organisations. The 'private sector' covers a very wide range of commercial interests inside and outside Hong Kong, so this is a rather amorphous category and represents many different individual companies acting as partners (informed through collaboration) and potential investors.

It is entirely to be expected that the private sector is a key decision taker on research inception in some areas. Research in Business & Commerce was clearly informed by business as was research in IT and Production & Technology Transfer by industry. By contrast we see Public & Social Policy, Education & Community Services and Health & Healthcare research identifying particular engagement with government departments and NGOs.

Art & Culture primary decision taker groups that were involved in the impact were government departments/agencies (17% ie 4/24), NGOs/third sector (13%) and the private sector (13%). The main forms of co-production and collaboration for them were international partnership (29%) and domestic partnership (8%). Education research was involved with government departments and agencies (45%), NGOs/third sector (27%) and politicians (11%), often through academic and public sector partnerships (45%). Similarly, Public & Social Policy engages with government departments and agencies (55%), NGOs/third sector (23%) and think tanks (19%).

An example is impact on the debate on healthcare reform and financing in Mainland China and Hong Kong of Public & Social Policy research led by The Education University of Hong Kong. Healthcare costs are rising with demand from a more prosperous and ageing population and a surge in non-communicable diseases. A key policy document on healthcare reform from the World Bank, WHO and the Chinese government extensively cited the research from The Education University of Hong Kong and this contributed to a debate that informed the Chinese State Council's Five-Year Plan (2016-2020).

The picture for Health & Healthcare and for Environment & Conservation is more diverse. The key decision-taker groups that were involved with Health & Healthcare were also government departments/agencies (34%) but the private sector was second (25%). This is similar to Environment & Conservation where government departments/agencies were the most frequently named decision-taker (28%) but equal second were the private sector and global political decision-makers (both at 16%).

By contrast, for Business & Commerce the key decision-taker groups were clearly the private sector (74%) while government departments/agencies (34%) ranked second, followed by NGOs/third sector (26%). This was a very similar picture to the Information Technology ICS with the private sector (63%) and then government departments/agencies (29%) and NGOs/third sector (21%). More surprisingly, although the priority of decision-takers was the same for Engineering, Energy & Construction, the frequencies were markedly lower: private sector (28%); government departments/agencies (11%); and NGOs/third sector (6%).

The mix of industry and government decision-takers that may be influenced by research is shown by two examples that were mediated by the Construction Industry Council (CIC), facilitating the link between research, companies and government. The University of Hong Kong worked across 34 construction sites to develop evidence-based guidelines requiring breaks for workers via a model that drew on weather forecasts to predict heat strain. This informed the 2013 "Guidelines on Site Safety Measures for Working in Hot Weather" issued by the CIC and now mandated by the Hong Kong Housing Authority. The Hong Kong Polytechnic University used data from a study of the cooling properties of different fabric types to make recommendations for construction worker clothing that protected them from heat stress with a 29% reduction in heat storage and a 14% improvement in thermal comfort. The uniform was licensed in 2015 to the CIC and later specified by the Government as standard work wear for all public works contracts (2018). More than 116,000 anti-heat stress shirts and 36,000 pairs of trousers have been sold to over 100 organisations and the standards have been adopted in other industrial sectors and in Cambodia and Saudi Arabia.

What is the scope and range of research impact?

The range of research impact that delivers benefits can be considered descriptively as a separate issue from the categorical questions of which research discipline is involved and what type of impact is delivered.

It is challenging to quantify impact, and almost impossible to do so in a comparable way because the scope and scale of the underpinning research is so diverse. A technology or a health project may deliver outcomes that are quantifiable in terms of people at risk, units sold, profits acquired or people treated, but only once the project reaches maturity: the 'end of the pipeline'.

Some projects at an advanced stage of development may show promise but that cannot be validated. An example is the development of anti-cancer drugs by a team at The Hong Kong Polytechnic University. These are in various stages of clinical trials and have received more than US$40m of investment from pharmaceutical companies. One drug has been licenced for US$5m. Some 30 jobs have been generated locally. Whilst no clinical impact can yet be measured, the activity of drug development is itself generating economic benefit.

Quantifying the scope of cultural impacts can be particularly challenging yet the benefits of such research has been demonstrated both in Hong Kong and globally. A researcher based at The University of Hong Kong mediated an exhibition, 'Rising Above', which attracted 13,600 people to the world's largest private collection of African American art and history outside the US. Meanwhile, City University of Hong Kong's use of virtual/augmented reality to showcase specific cultural heritage forms had an evident global reach. It was first used in Australia and then exhibited at 48 international venues, including the Smithsonian (Washington, D.C.) and is now a permanent installation at Museums Victoria (Melbourne, Australia) and at the Centre for Art and Media (Karlsruhe, Germany).

Hong Kong may be particularly well positioned, by its history and culture, to mediate access and understanding between Eastern and Western cultural milieux. Hong Kong's cultural research also links to financial returns through tourism. Research at The Hong Kong Polytechnic University produced an accurate tourism demand forecast, not only helping businesses to formulate operational strategies for visitor arrivals from more than 40 Asia-Pacific locations but also enabling the China Tourism Administration (CNTA, now the Ministry of Culture and Tourism (MCT)) with tourist flow management between Mainland China, Russia, Mongolia and Pakistan.

Participatory visual Art & Culture research described by Hong Kong Baptist University led to changes in organisational behaviour and attitudes towards commissioning public art in government departments and art festivals across East Asia. The work reached 350,000 participants and developed new audiences and understanding in Hong Kong, South Korea, Japan and Taiwan.

ICS databases can reach beyond original targets. The 'Multi-function Chinese Character Database' developed by researchers at The Chinese University of Hong Kong facilitates teaching and learning by tracing the genealogy of Chinese scripts alongside innovative visualisation (such as "componential trees/formulas"). Released in 2014, the database has recorded over 10 million accesses and over 60 million searches at a daily average of 32,000+ searches. Peak database simultaneous access is as high as 500 users of which the teachers at whom the database is aimed only account for one-third.

Education & Community research delivers not only in schools but also in youth services. One notable example involved research from The Chinese University of Hong Kong that led to higher youth physical activity levels through the familiar activity of rope skipping. Some 390,000 individuals from 340 schools benefitted from this moderate physical activity which is now promoted in government-led health campaigns. In addition, several Hong Kong world champions and elite athletes were developed delivering 311 medals in the Asian and World championships.

An innovative 'positive youth development model' tackles challenges facing adolescents (such as anxiety, depression, and substance abuse). This project, developed by researchers at The Hong Kong Polytechnic University, was aimed at high-school students in Hong Kong but its success meant it was adapted as an intervention model in 237 schools and benefitted more than 73,000 adolescents 2013 and 2019. In another ICS, researchers at City University of Hong Kong developed welfare and restorative solutions for at-risk youths. These were taken up by government policies, and practice models that benefitted tens of thousands of young people, their families and teachers across Macau, Hong Kong, and Singapore.

Some impacts produce savings rather than revenue. The Hong Kong Polytechnic University improved productivity and innovation and lowered employee turnover. This work led to one large company reducing staff turnover by 36% while a second increased employee proactivity and boosted patent applications by 50%.

Hong Kong research impact percolates outside the region, sometimes with significant effect. Researchers at Lingnan University working on the evolution of competition policy created significant regulations for Mainland China's 2018 Anti-Monopoly Law and had a direct effect on competition law enforcement in Mainland China. New merger control regulations have evaluated more than 3000 merger notice cases since 2018 and led international best practice in the field. The Chinese University of Hong Kong examined Mainland China's one child policy and showed that its impact on the health and education outcomes of children were modest but that it had adverse effects on other indicators such as crime rates. The research contributed to public and media debate and, although difficult to attribute the research directly, the debate resulted in a move to a two-child policy.

Health & Healthcare research had impacts on drug development, clinical guidelines, diagnostic tests, screening programs, infectious disease and mental health. There were also case studies on Chinese and herbal medicine and case studies where other disciplines impacted on health, e.g., a space camera system used in surgery.

In this research, undertaken by a team of engineers at The Hong Kong Polytechnic University (submitted to UoA14: mechanical engineering, production engineering, textile technology & aerospace engineering), innovative use was made of a camera pointing system used by the Chinese National Space Administration in its Chang'e-3 and Chang'e-4 moon missions. The technology was transferred to a start-up, NISI (HK) Ltd., which repackaged the system's materials' properties, design and mechatronics in a reduced-size, light-weight robotic unit, smaller than current commercial systems and capable of providing tactile feedback enabling high-precision minimal/non-invasive surgery.

The Chinese University of Hong Kong developed Fibroscan, a non-invasive test for liver fibrosis. The test is now widely used as the recommended diagnostic approach in international clinical guidelines. In Hong Kong, as a result of this innovation, the number of liver biopsies has halved over the past 5 years, generating an estimating cost saving of around HK$13m (cUS$1.7m) a year.

The link from biomedicine to Information Technology is increasingly important. The Hong Kong University for Science and Technology developed an innovative direct-to-consumer DNA ancestry testing platform facilitated through WeGene, a personalized healthcare testing provider. WeGene grew from 8,000 customers in 2016 to about 300,000 customers in 2019 and its work attracted global attention on Asian heritage and health issues.

Optics have versatile applications. Another camera-based ICS was produced by former PhD students from City University of Hong Kong. They developed a computerized camera for real-time acquisition and processing of 3D objects. The spin-off company, Orbbec Co. Ltd, is headquartered in Shenzhen and is now a leading provider of 3D sensing solutions with over 300 employees, annual revenue of US$100 million and valued at over US$1 billion.

Environment & Conservation research had diverse impacts across pollution, health, sustainable agricultural practices, and community building. Researchers from the department of Biomedical Sciences at City University of Hong Kong established a test for endocrine disrupting chemicals (EDC) which are common in consumer products although potentially harmful to reproduction and behaviour. Their 'Glowing Medaka Test' uses a biotic reaction as a fast and low cost test for EDC to identify previously unknown toxicities in products from cosmetics to baby nutrition. The technology is now applied commercially.

The development of a cheap and reliable histamine detector based on research by City University of Hong Kong should facilitate reductions in severe dietary reactions, such as asthma and hypotension. The work generated RMB20m (cUS$3m) investment from government and industry; spin-out XMinnov Ltd employs 10 full time staff for commercialization; and the technology is being used by Xiamen Entry-Exit Inspection and Quarantine Bureau for pre-screening of histamine in food.

The continuing importance of basic research in agriculture to produce more food and to enable crops to adapt to challenging conditions is highlighted in several case studies. A unique rice irrigation method was developed by a Hong Kong Baptist University researcher who had

observed in childhood that minimal irrigation after flowering led to enhanced yield. Using this observation, his team developed and tested the Alternate Wetting and Drying (AWD) irrigation technique. This redirects pre-stored carbon reserves in the rice stem to grain filling, delivers a 10% increase in grain yield and reduces water use by 30%. Quantified impact from Jiangsu Province, China, shows this has increased farm income by over RMB 4 billion (US$600m).

Salt and drought-tolerant soybeans have been developed by researchers at The Chinese University of Hong Kong. Sustainable farming is now benefitting from genomic research on soybeans that included both whole genome sequencing and then the identification of specific traits. Research findings enable gene marker-assisted selection for salt tolerance and field evaluation for drought tolerance. The team successfully bred three new salt and drought-tolerant soybean cultivars (Longhuang 1, 2, and 3) with a current estimated accumulated acreage exceeding 12,400 hectares (Gansu Province, China, 2016-2019) and an estimated financial benefit of RMB 3.12m (US$476m).

Information Technology delivered benefits not only in computing and mobile technology but, as noted, in genetic and health technology and in transport and other technology sectors. One notably impactful ICS was the development of an algorithm to support flight control systems for drones. Whilst studying for a Master's degree at The Hong Kong University of Science and Technology, the researcher conducted initial research on autonomous flight control systems for unmanned aerial vehicles (UAVs). He developed an unmanned miniature helicopter that achieved the world's first flight on Mount Everest. Work to improve the flight controller led the researcher to commercialize drones through the founding of DJI Technology and integrate the flight control system and navigation technology. The improved performance enabled DJI to become the world leading manufacturer of UAVs. In 2017, DJI reported revenues of RMB18 billion (cUS$2.8 billion).

Engineering, Energy & Production delivered benefits through four dominant subthemes: sustainability; standards and accreditation; health and safety; and safe building design. The Hong Kong Polytechnic University's Building Energy Group advised on over twenty projects, including signature buildings such as the International Commerce Centre. Drawing from their research on the optimal design of air conditioning systems, the integration of renewable energy and the development of smart energy efficient control strategies they estimate energy savings ranging from 15% to 42% totalling over 25 million kWh annual savings, currently valued at about HK$25 million (cUS$3.2m).

Commerce and travel are vital to Hong Kong. In transport, researchers at City University of Hong Kong developed an intelligent sensor system which is used for the roughly 260 million passengers who pass through the immigration gates in Hong Kong. The sensor is used at the HK immigration gates, which has been generating a yearly revenue of more than HK$10m (cUS$1.3m) since 2013. In food logistics, City University of Hong Kong developed a composite material based on a by-product from the sugarcane industry, designed to replace environmentally damaging plastic food packaging material. This product has been demonstrated to be gas-, heat-, oil-resistant, and 100% biodegradable.

How long does it take for research to deliver impact?

The research papers cited in support of research leading to impact were published with an overall median date of 2015 that varied only slightly between clusters (Table 2). The tendency towards 'recency' in publications has also been noted in the UK REF data and suggests that case study authors tend to focus on later discovery than earlier 'underpinning'.

Impact timeframes should also be seen in the context of much earlier research by Griliches and Mansfield,[5] from which research policy studies over many years have concluded that a typical 'lag time' between discovery and subsequent socio-economic impact appears to be about 17 years.[6]

Table 10: The time span of research leading to impact, for 11 thematic clusters of Impact Case Studies.
The dates shown are those recorded in the case studies as the onset of the research described by the researchers.

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
ICS count	12	24	17	44	35	31	64	25	24	36	30
Earliest date	1965	1979	2000	1989	1995	1980	1988	1995	1999	1990	1997
Quartile 1	2001	2005	2005	2000	2006	2000	2000	2001	2003	2004	2005
Median	2009	2010	2010	2004	2010	2005	2005	2003	2011	2010	2006
Quartile 3	2012	2012	2011	2012	2010	2011	2009	2006	2014	2013	2010
Latest date	2014	2015	2016	2013	2014	2016	2015	2015	2017	2016	2017

'Total mentions' is the number of times this category (here 'stakeholder') is coded within the 11 themes. This is the total of the subcodes in the table.

[5] Griliches Z. (1979). Issues in assessing the contribution of research and development to productivity growth. The Bell Journal of Economics 10(1): 92-116. Mansfield E. (1972), R&D's contribution to the economic growth of the nation. Research Management 15(3): 31-46.

[6] Morris ZS, Wooding S & Grant J (2011). The answer is 17 years, what is the question: understanding time lags in translational research. Journal of the Royal Society of Medicine 104:510-520. [journals.sagepub.com/doi/full/10.1258/jrsm.2011.110180]

However, such analyses have historically been sparse and specific. It is also the case that most innovation draws on multiple discoveries and some key discoveries have a diverse range of impact, so the establishment of a single 'critical' timeline is arguable. Furthermore, the effect of serendipity cannot be discounted, where established knowledge is shown much later to throw light on a previously unconnected problem.

Analysis of the text within the ICS revealed some dates for the start of the research, or the origin of the underlying concepts, that precede cited references: the earliest for any ICS was 1965 in Heritage & Tourism. There is some time-spread across themes with only two (Chinese Language, Translation & Interpretation and Information Technology) having an earliest ICS start-date as recent as 1999/2000. Median dates for different ICS were generally in the mid-2000s and analysis of the third quartile for the date range suggests that research for three-quarters of the studies had started at least ten years ago. (Table 10)

The research leading to described impact in both Art & Culture and Chinese Language, Translation & Interpretation started on average in 2010 (i.e., the median quoted in the ICS), which indicates that research in these clusters had a shorter time lag than average between the start of the research and the start of the impact assessment period (1 October 2013). The median publication date for these clusters was 2015, however, which mirrored the publication date for the whole sample. Heritage & Tourism was slightly ahead of these areas, with an average research start date in 2009 and a median publication date of 2013. By contrast, while Business & Commerce research also started in 2010 on average, its median publication date was slightly later, in 2016.

The ICS in the Education & Community cluster identified an average research start date that was earlier than the humanities clusters (2004) but the median publication date (2014) was broadly similar. These dates are similar to those for Public & Social Policy and Health & Healthcare, both starting in 2005 on average and with a median publication date of 2015.

For the Environment & Conservation cluster, underpinning research started in 2003 on average, indicating a comparatively long lag between the start of research and the start of impact, and the median publication date was 2013, also slightly earlier.

Among engineering and technology clusters, the earliest average start date was among the Production & Technology Transfer ICS (2006) and the earliest dates for any ICS were comparatively recent. On average, Information Technology ICS started in 2011 on average and Engineering, Energy & Construction ICS started in 2010 which is later than the averages for both Health & Healthcare and Environment & Conservation. Median publication dates for all the technology clusters were around 2015.

The differences in average time-lags in these case studies appear to reflect the greater time lag between the start of a research program and the achievement of evidenced impact for experimental sciences. Although it would be unwise to over-generalize, research in the social sciences and engineering is 'closer' to an evidently valuable innovation or a potentially addressable challenge whereas research in the natural sciences is by its nature more speculative and exploratory. The time-lag that can, at the point of impact, then be traced back for basic scientific research will tend to go to an earlier 'origin' than for any applied research.

Where does research impact happen?

The spread of impact can be considered from a series of perspectives, which we follow here.

First, how much does Hong Kong's research have global impact and where does that occur? Second, which economic and social sectors in Hong Kong are likely to gain from the research of its universities (and thereby act as mediators for further benefit)? Third, which social and economic groups are the ultimate beneficiaries of this work?

Table 11: The global spread of impact from research in Hong Kong universities. Data shown are counts of impacts described in the 342 Impact Case Studies in RAE 2020 and any one case study may have multiple impacts.

Continent	Instances	%
Asia	823	65.7
Europe	195	15.6
North America	140	11.2
Oceania	57	4.6
Africa	27	2.2
South America	11	0.9

Around two-thirds of the impact described in the case studies is realized in Asia, predominantly in the Asia-Pacific region, as illustrated in Table 11. The other two regions gaining a significant impact benefit are Europe and North America and this matches the regional spread of both academic and pharmaceutical/industrial collaborative partnerships identified by the researchers. For example, 3000 products use the Qi standard for wireless charging developed by a City University of Hong Kong start-up company (instrumental in founding the Wireless Power Consortium) including those from major companies such as Apple, Huawei and Samsung. Such partners are normally essential for the effective mediation of impact at any distance.

The distribution of impact by region is a broad reflection of, first, global research excellence as well as regional proximity and, second, the accessibility and likelihood of potential research and development partners. (Table 12)

Research from Hong Kong is producing some specific benefits to Mainland China's investment practice. Research from The Hong Kong University of Science and Technology on stock valuation and investing were applied to China Investment Corporation (CIC), the second-largest sovereign wealth fund of its sort, which manages more than US$940 billion in assets. A new quantitative system to manage the fund's multibillion-dollar equities portfolios has produced financial gains for the company and Mainland China as a whole.

Table 12: The regions most frequently cited as impact beneficiaries of research described in 342 Hong Kong Impact Case Studies in RAE 2020. Any one case study may have impact in multiple regions.

	Total	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
ICS count	342	12	24	17	44	35	31	64	25	24	36	30
Hong Kong	257	10	23	15	39	29	24	45	17	13	29	13
Greater Bay Area (excl HK)	11	0	0	2	0	0	0	1	2	1	2	3
Mainland China (excl GBA and HK)	42	1	1	0	2	2	4	10	4	3	2	13
USA	110	2	8	5	7	11	6	35	5	7	9	15
UK	57	2	9	3	4	4	5	17	0	4	5	4
Singapore	44	1	4	4	7	6	4	10	0	1	4	3
Australia	40	3	4	3	6	5	3	10	0	2	2	2
Japan	38	0	9	3	4	1	0	8	2	1	4	6
South Korea	28	0	5	0	7	2	2	6	2	0	2	2

It is unsurprising that research in Health & Healthcare has a wide global reach, since this can be linked not only to partners in other research institutions and in health sector companies but also to international organizations such as WHO. Environment & Conservation also has a significant impact link to the USA, which has excellent academic research in these areas. However, the global research of Art & Culture is more intriguing: this partly reflects both international interest in Chinese history and culture, where Hong Kong is in a strong position to interpret accessibly, and partly the pro-active work of Hong Kong academics through touring exhibitions and presentations.

It is evident that Hong Kong is a frequent research partner in those regional economies that have a well-established reputation for research excellence (Singapore, Australia, Japan and South Korea). These partnerships will be delivering high quality research outcomes and this amplifies the impact of Hong Kong's own research capabilities. The regional reach can be substantial: for example, a case study from The University of Hong Kong details the world's first dental age assessment dataset for Asian ethnicity that has led to accurate age estimation for 252 previously undocumented children in India and Mainland China. Regional training more than 300 dentists and forensic practitioners has enabled birth registration and access to schooling and health care for hundreds of previously excluded children.

Some research has truly global impacts. The development of robust methods for the synthesis of different noble metal nanocrystals by researchers from the Chinese University of Hong Kong was subsequently employed by three spin-out companies. This technology has reached over 1000 customers in more than 30 countries and regions and has been used in R&D in medicine, diagnostics, biotechnologies, optical and optoelectronic devices, in detection methods for monitoring the quality and safety of foods, beverages, drugs and explosives.

What benefits are delivered in Hong Kong?

There are 21 work sectors in the Hong Kong Standard Industrial Classification, of which only 19 of them were mentioned in the ICS. Some of these sectors receive benefit from research in several clusters while in other cases there are more specific relationships.

Engineering, Energy & Construction had a more widespread impact across construction (42%), logistics & transport (28%) and energy (17%). Production & Technology transfer influenced manufacturing (50%), commerce (43%), information and communication services (27%), and the health & social sector (27%).

The Social sector and Education sector both derive benefit from research in multiple sectors and thus each have a substantial tally of ICS. However, it is likely that many of these benefits are diffuse and are realized across a large population, whereas more specific examples may be more concentrated in benefit value.

Glossary to sector names

Formal Hong Kong sector label	Short label for Table
Accommodation and food service activities	Hospitality
Activities of extraterritorial organisations and bodies	Extraterritorial
Agriculture, forestry and fishing	Natural resources
Arts, entertainment and recreation	Arts sector
Construction	Construction
Education	Education
Electricity and gas supply	Energy
Financial and insurance activities	Finance
Human health and social work activities	Health & social sector
Import/export, wholesale and retail	Commerce
Information and communications	IT & Communications
Manufacturing	Manufacturing
Mining and quarrying	Extraction
Professional, scientific and technical activities	Research
Public administration	Public administration
Real estate activities	Real estate
Transportation, storage, postal and courier services	Transport & Logistics
Water supply, sewerage, waste management, and remediation activities	Environmental services
Work activities within domestic households	Domestic

Table 13: The impact of university research on economic sectors mentioned within ICS at Hong Kong RAE 2020.
BOLD cells are those where the number of ICS referencing benefits to that sector exceed 10% of the total ICS for that cluster.

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer	Total
Total ICS	12	24	17	44	35	31	64	25	24	36	30	342
Total mentions	21	30	28	75	49	49	97	35	37	48	55	524
Hospitality	0	0	0	0	0	0	0	1	0	0	0	1
Extraterritorial	1	0	0	1	1	3	6	1	0	0	0	13
Natural resources	0	0	0	0	0	0	1	5	0	0	1	7
Arts sector	**9**	**22**	**7**	5	1	2	0	1	2	0	0	49
Construction	1	0	0	0	0	0	0	1	0	**15**	0	17
Education	**4**	**6**	**12**	**31**	1	4	2	0	1	1	0	**62**
Energy	0	0	0	0	0	0	0	1	0	**6**	1	8
Finance	0	0	0	1	**18**	3	0	1	3	0	2	28
Health & social sector	0	0	**5**	**24**	0	**8**	**60**	**7**	3	1	**8**	**116**
Commerce	0	0	0	0	4	0	7	1	0	1	**13**	26
IT & Communications	0	1	2	4	1	1	3	0	**14**	2	**8**	36
Manufacturing	0	0	0	0	1	0	**10**	1	2	3	**15**	32
Extraction	0	0	0	0	0	0	0	0	0	1	0	1
Research	**4**	1	2	2	**15**	3	5	1	**7**	2	2	44
Public administration	0	0	0	6	**6**	**24**	2	**4**	1	**5**	1	49
Real estate	0	0	0	0	1	0	0	0	0	0	0	1
Transport & Logistics	1	0	0	0	0	1	1	0	**4**	**10**	1	18
Environmental services	1	0	0	0	0	0	0	**10**	0	1	3	15
Domestic	0	0	0	1	0	0	0	0	0	0	0	1

'Total mentions' is the number of times this category (here 'sector') is coded within the 11 themes. This is the total of the subcodes in the table.

Some of the locally delivered benefits are very substantial:

HK$13 million
(US$ 1.6m) savings to public health system in HK due to development of a non-invasive test for liver fibrosis

20 million
People watched televised lectures on East-West cross-cultural understanding and misconceptions

4,270
(Estimated) children who did not have toothache due to the development silver diamine fluoride (SDF) solution to manage tooth decay

RMB4 billion
(US$600m) - increase in farmer's income in Jiangsu Province due to the adoption of Alternate Wetting and Drying (AWD) irrigation technique during the entire rice growing season.

20,000
Teachers and students benefited from a model for teaching meditation to students and educators in secondary schools

US$1.5 billion
Annual revenues for entecavir (Baraclude™), a drug tested by HK researchers as an alternative treatment for hepatitis B

25 million kWh
Annual savings (worth HK$25m) from optimised design of air conditioning systems, the integration of renewable energy and smart, energy efficient control strategies

US$2.83 billion
Annual revenues for DJI Drones in 2017, a company started by a HK university Master's student based on the research undertaken as part of his studies

Some 60 of the 97 mentions from the 64 ICS in Health & Healthcare ICS benefitted the Hong Kong Human health and social work sector. The importance of research based specifically in Hong Kong is exemplified by a project from The Chinese University of Hong Kong. This has improved mental health service for children and adolescents by 're-norming' a number of clinical assessment tools and protocols that had been developed in the West. The team reviewed a series of protocols for the assessment and diagnosis of mental disorders and amended these in the light of Asia specific issues. They estimate that about 10% of all 6-17 year-olds now use the updated protocols at some point in their adolescence.

An excellent and less anticipated example is a project from Hong Kong Baptist University that focused on medical interpreting services in Hong Kong. As in many countries, ethnic minorities have language difficulties in accessing healthcare services without costly interpreters. The underpinning research showed that most interpreters received no training specific to medical settings. This led to policy changes and the Hospital Authority now stipulates the provision of medical interpreting training courses. By 2017, over 100 interpreters with 17 language backgrounds had been trained and subsequently delivered targeted interpreting in over 10,000 cases.

Who are the social beneficiaries of research impact?

The ultimate beneficiaries of public research investment should be the public: a return on the tax revenue invested through wealth creation and the quality of life.

Increased company profitability improved public health and welfare, and a culturally and knowledge enriched environment spread a variety of benefits, some evident and some less tangible, to different social groups.

Table 14: Beneficiary groups of research carried out by Hong Kong universities and identified in the 342 Impact Case Studies submitted to RAE 2020, grouped by 11 thematic clusters. Significant groups are in **BOLD**.

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
Total ICS	12	24	17	44	35	31	64	25	24	36	30
Total mentions	11	22	20	90	9	8	64	10	16	2	17
University students	0	**5**	**4**	**7**	1	0	0	1	2	0	0
Patient groups	0	1	0	0	0	0	**34**	0	0	0	5
Carers	0	0	0	1	0	0	3	0	0	0	0
Children (under 18)	3	**8**	**8**	**34**	0	0	**11**	1	1	1	1
Citizens/communities	**6**	**6**	**4**	**14**	**6**	2	2	3	**12**	0	3
Disabled People	0	1	2	4	0	0	1	1	0	0	3
Elderly	0	0	0	2	0	3	5	1	1	1	2
Families/parents	0	0	0	**10**	0	0	0	1	0	0	1
Marginalised communities	0	1	2	**12**	1	0	2	1	0	0	0
Refugees	0	0	0	1	0	1	0	0	0	0	0
Gender-based groups	0	0	0	1	1	2	**6**	1	0	0	1
Other	2	0	0	4	0	0	0	0	0	0	1

'Total mentions' is the number of times this category (here 'beneficiaries') is coded within the 11 themes. This is the total of the subcodes in the table.

Although it will be evident to any reader of the ICS that the research implicitly delivers 'public' benefit, it can be challenging to identify specific beneficiary groups with certainty. The analysis for this report takes a relatively conservative view and highlights only those groups specifically mentioned by the case study writers. The data in Table 14 therefore under-records true impact; for example, there are only two mentions of citizens and communities in Health & Healthcare compared to 12 in Information Technology. Similarly, in an example quoted earlier in this report, the research led to the production of 2,700 uniforms specially designed to protect against extreme heat and distributed to construction workers in Macao yet, although the benefit is clearly substantial, citizens do not appear as a social beneficiary group in that ICS. It is likely that this is because the academic ICS writers focus their research on specific impact, to patient groups or to products, rather than recognising the broader impact that their work delivers.

A valuable example from an unexpected quarter came in the Production & Technology Transfer cluster. This relates to medical technology, where City University of Hong Kong details research on ultrasound-based non-contact motion sensors and biopotential sensing technology for disease diagnosis, ambulatory monitoring, and rehabilitation. This has been used for applications such as surgery assistance and interactive modules in public and commercial exhibition platforms. Thus this not only has technological and medical impact but also delivers an evident societal benefit.

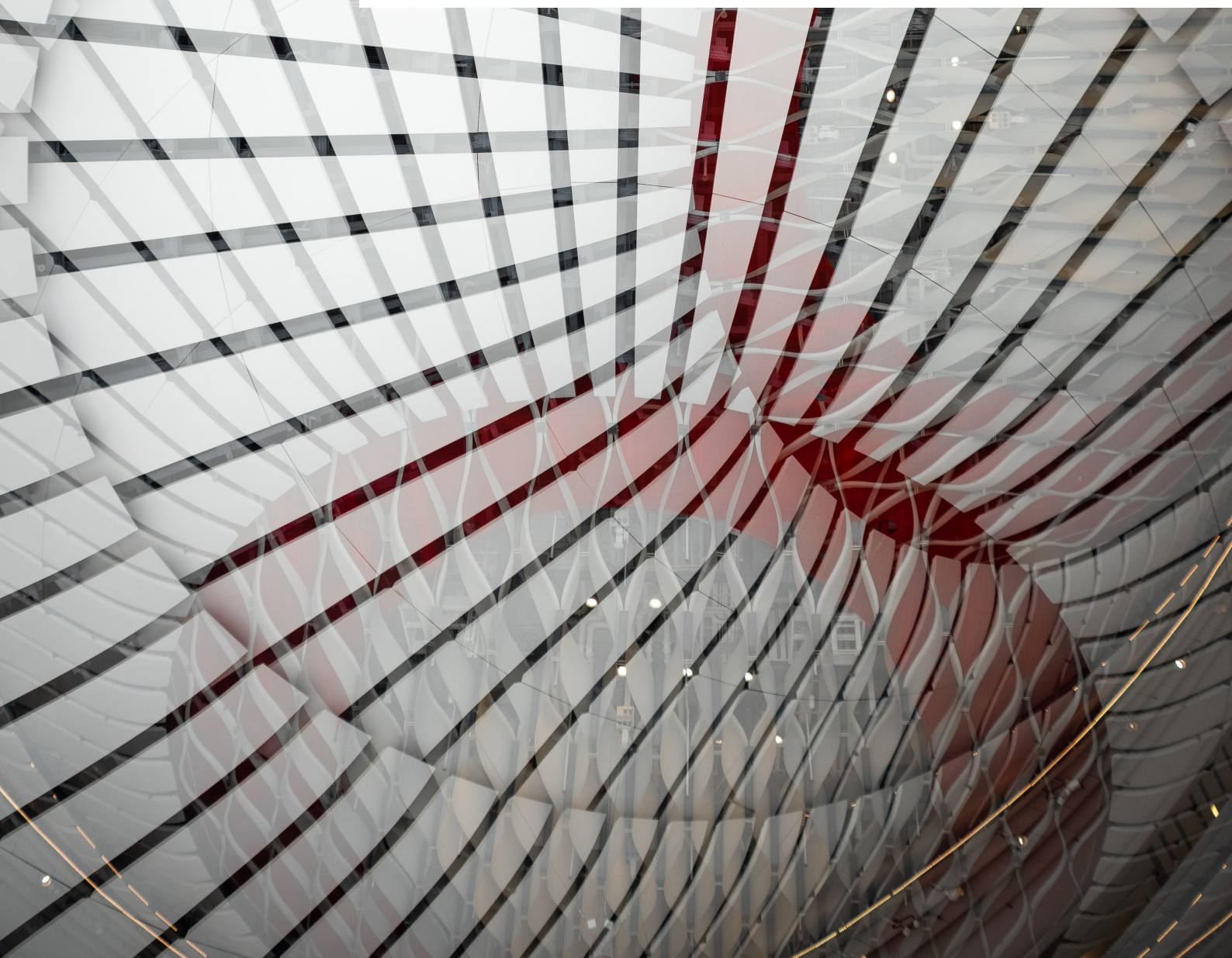
Education & Community Services key socioeconomic target group were children (77% ie 34/44) in addition to citizens/communities (32%) and marginalised and minority communities (27%). In addition, note that Chinese Language, Translation & Interpretation had a significant impact on children (47%) as well as citizens/communities (24%).

Two-thirds of Public & Social Policy ICS mentioned impacts through law, politics and community services and one-quarter via the economic framework. However, the mentions of the key socioeconomic group who must have benefitted from this were much sparser: elderly (10%), citizens and communities (6%); and women and gender-based groups (6%).

Hong Kong's strategic priorities

Evidence derived from the ICS and from the bibliometric analysis shows that the research of Hong Kong's universities is diverse, excellent and well connected and is therefore likely to provide the foundations for supporting the administration's strategic priorities.

Continuing research value will best be ensured if universities continue to be able to support these priorities by: delivering high quality research; supporting high impact research; making use of mechanisms to facilitate multidisciplinary research; and sustaining international collaboration.



Hong Kong universities' research impact ranges from both local and international impacts of research in art and culture, through both global and Asian-specific medical innovations to the cross-disciplinary benefits of linking medical and social research with new technology. Many of the examples quoted earlier and in the thematic reports are of global interest and value. Some outcomes were the clear focus of persistent research endeavour; others were almost serendipitous. The ability to use opportunities is the consequence of having a well-informed research background.

In its strategy, it is suggested that the Hong Kong government identifies building blocks to embrace nine opportunities and challenges associated with a compact high-density city.

- Growing and ageing population; shrinking labour force
- Imbalanced spatial distribution of homes and jobs
- Large quantity of old building stock
- Keen global and regional competition; our strategic positioning in the GBA
- Enabling innovation and technology to enhance productivity
- Responding to climate change
- Providing new transport and other infrastructure
- Meeting long-term land requirement
- Enhancing liveability

As noted in this and the thematic reports, some of the ICS address this directly, through research on agricultural food efficiency and food safety, mediating social challenges, increasing automation, innovative technology, addressing issues for both specific and general health and for the quality of the living environment, and enabling people to better understand and benefit from the rich and diverse culture in which they live and work.

Other case studies create the conditions in which this can happen. Few of the nine opportunities and challenges could readily be addressed by any one research area. Many specific requirements will only become apparent in time. They will need to be approached from multiple perspectives that will draw on cross-disciplinary research. The thematic reports include many examples of such interdisciplinary or 'cross-over' outcomes where one research area has drawn on or exploited an innovation originally spawned in a different discipline: examples include health-technology innovation.

The bibliometric analysis showed that the research output of Hong Kong is expanding and improving in quality relative to global benchmarks. The case study analysis shows that this research is diverse and is already addressing a multiplicity of local, regional and international challenges and that this is being done with a multiplicity of private sector, public organisation and leasing academic partners. This is an excellent platform for future innovation, development and application.

Recommendations for next cycle

The conclusions of the analytical team, having read the content of the ICS, coded the information and assigned additional metadata to each study for further analysis, is that the process had generally worked well.

The information provided by researchers was informative and suggested a sound understanding and interpretation of the purpose of the ICS process and an awareness of relevant activities. These were presented in ways that demonstrated their contribution to impact and the significance of that impact clear to the reader. While few quantitative data asserted by the researchers could be checked and validated, the values all seemed in line with what might reasonably be expected.

The structure of the exercise could be modified to improve analytical power. The numbers per panel (and even more so per year) are relatively small, but a smaller number of larger panels would reduce the coherent academic sense of the information. However, the template for the ICS submissions could be modified so that specific information (e.g., on location, or on quantitative impact) was presented more consistently with benefits to comparative analysis.

Much of the research that led to significant impacts was evidently interdisciplinary. It may be asserted that any cross-disciplinary activity is more difficult for traditional discipline-based panels to evaluate. We do not believe that is the case since this aspect of research 'downstream' from curiosity-driven origins will be familiar to expert reviewers. The analytical approach that was taken, using topic modelling, allows the data to drive the analysis rather than fitting the work into pre-set categories.

It was evident that the topics emerging from the ICS were supportive in addressing the strategic priorities set by the Hong Kong administration. The bibliometric analysis confirmed that there is a sound platform of high-quality research activity that will sustain further innovation and impact. It might be thought appropriate for future assessment cycles to ask more direct questions about the relationship between an ICS and these priorities. We would urge caution in doing this lest it drives a research reorientation towards an agenda of predetermined objectives rather than the rich pattern of discovery and development presently encountered.

Annex 1: Background

The development of research assessment

The first national assessment of a public-sector research base was the Research Selectivity Exercise introduced by the UK University Grants Committee in 1986.

Prior to the 1980s, most countries that had significant public sector research funding only evaluated proposals submitted by principal investigators as part of a process by which relevant bodies awarded research grants. Assessment of the benefits was generally limited, since it was accepted that research is, by its nature, an unpredictable and uncertain process and research support had generally been sufficient to meet high quality proposals.

The European Commission's Framework Programmes did make wider use of assessment, at the start, during and at the end of both projects and wider initiatives. This established a general notion of tracking both research progress and outcomes. Wider economic and political changes in the 1970s and 1980s stimulated national considerations of research assessment as part of a shift towards greater selectivity. First, the oil crisis of the 1970s severely impacted the capacity of western economies; second, the growth of the research base in G7 countries meant that researcher demands were beginning to exceed resource supply.

The UK's 'selectivity' exercise was explicitly intended to identify more or less excellent parts of the national research base and to concentrate core higher education investment on those institutions that had evidenced a sound return. At the same time, the Research Councils, which directed individual grants, were expected to take note of the new information in deciding which proposals to support.

This exercise, and its reiteration in 1989, began a process of cultural change in the system and structural change in the institutions. The New Higher Education Funding Councils, which replaced the UGC in 1992, adopted the concept and reified it in the first fully structured Research Assessment Exercise (RAE). The RAE became cyclical and was repeated in 1996, 2001 and 2008 before evolving into the Research Excellence Framework in 2014.

By the mid-1990s it was widely accepted among the UK's research partners that the RAE had stimulated a shift in attitudes to research and an improvement in comparative national performance. The RAE model was discussed and reviewed by many national academies and research ministries. Hong Kong was among the first jurisdictions to adopt a similar process, covering all research subjects in all institutions on a cyclical basis. New Zealand's sister process was the Performance-Based Research Fund (PBRF) which has been running cyclically since 2003.

Australia considered a number of variants before juggling the RAE acronym and instituting 'Excellence in Research for Australia (ERA)' in 2009.

Other countries have piloted other forms of national research assessment but have prosecuted this less consistently and cyclically. For example, both France and Germany carried out comprehensive national evaluation across higher education institutions and research institutes in the early 2000s, leading to major structural changes and funding shifts, but did not then adopt regular assessment cycles. The Czech Republic and Poland have both explored and described possible national research assessment but not then proceeded to implementation. Canada carries out research assessment in health and education that is often quoted as an international exemplar, but this is not applied in other disciplines. Ireland has carried out national evaluation centrally but has not done this in concert with institutions.

The public policy agenda for research continued to evolve. The emphasis in the 1980s and 1990s was firmly on 'internal' academic research excellence, to support the highest quality of innovative and fundamental research. The emphasis in recent years has shifted towards the 'external' impact of research on society and in the economy. This is in part a shift from 'what do we want to invest in?' towards 'what do we get for our investment?' and in part a response to further demands and restrictions on public funding generally.

A key consequence was the UK shift from the RAE structure to the REF in 2014, introducing the 'Impact Case Study' (ICS) as a tool for assessing the external research achievements of funded HEIs. An analysis of 6,679 ICS submitted to REF2014 found that the societal impact of UK HEIs' research was considerable and diverse. Multiple fields of research underpinned each ICS, leading to multiple types of impact. The quantitative evidence supporting claims for impact was diverse and inconsistent, however, suggesting that robust impact metrics were problematic. Numerical data was abundant but presented in conflicting forms, scales and units and comparative metrics could not easily be calculated. ICS did allow researchers to select specific data to evidence the impact they claim and provided a rich resource for analysis, but the data are collected for assessment, not analysis: these two purposes may play against each other.[7]

REF2014 demonstrated the value of the ICS methodology and showed that it could not easily be duplicated by any simple data collection. The ICS that formed a key part of changes to the structure of Hong Kong's RAE 2020 are the focus of this report.

[7] The Nature, Scale And Beneficiaries of Research Impact: An Initial Analysis of Research Excellence Framework 2014 Impact Case Studies - Available at www.kcl.ac.uk/policy-institute/assets/ref-impact.pdf

Annex 2: Glossary

Beneficiaries: Those who benefit from the research described in an ICS and specific to an impact.

Changing policy and governance: Governing policy or legislation has been informed. This can be a change or alteration made to a policy based on research findings or mechanism, or a new policy is developed. Does not include institutional policy, does not include privately led policy.

Changing processes and practices: Processes and practices have been informed. This can be a change or alteration made to an institutional policy or practices based on research findings or mechanism, or a new practice developed.

Changing public debate and perceptions: A modification, alteration, or change to common knowledge on a matter. Does include public engagement in new information, does not include the act of disseminating information (see 'mechanisms')

Codification: New idea /product / invention formally registered (e.g., software or medical inventions or expert recommendations to gov/ industry and the implementation of that recommendation is monitored).

Co-production & collaboration: Shared knowledge translated between academia and adopter community / policy makers / industry / other forms of partnership, excluding academia which influences the impact of research.

Disseminating research findings: The methods used communicate the research outputs, and the different types. Does not include the outcomes from dissemination. Does not include the impact of dissemination.

Decision makers / influencers: Those groups who were informed by the research in taking a decision (i.e., a policy maker used research to inform new policy).

Economic changes: The research has translated into a commercial output or outcome, or there has been some change to resources or economy.

Elapsed time: This is a simplified version of Hanney et al (2015)'s 11 calibration points that were effective in measuring and understanding the impact of health research. It is based on the year of publication of main research findings and the year of main impact.

Hong Kong Standard Industrial Classification: These are the Hong Kong Standard Industrial Classification Version 2.0 (https://www.censtatd.gov.hk/en/index_hsic2_code.html), based on the top level category. This is used to classify the application or utility of the research in terms of broad sectors.

ICS: This is used throughout the report as the short-form of Impact Case Study

Impact: For the purpose of the RAE 2020, impact was 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 whether locally, regionally or internationally; and that are beyond academia.

Impact type: The type of impact translated from the research output. This includes the impact itself but does not include the impact area in which the impact took place. From Williams 2020 and Williams and Lewis 2021 .

Impetus for research: The underpinning activities that led to the research. To understand why research was initiated, the research team coded for the external factors which led to new research discoveries. This includes the pull and push factors.

Pull Factors: In response to an existing problem, research is conducted to meet stakeholder demands (e.g., policymakers, industry, etc.). This can include requests for new data or better technology, research to fill an existing gap or resolve a conflict and commissioning reports and evaluations to incentivise policies.

Push Factors: Research conducted to promote information on a new concept or piece of work, take advantage of new knowledge and building on it, but where the research findings do not address a specific problem. Includes promoting particular research, proof of concept work, the place of individual brokers within social and policy networks, or even questioning the nature of the evidence in question.

Researcher Involvement: Mutually exclusive categories that address the question 'How is the researcher involved in the activity or mechanism?' (e.g., collaboration with sector).

Sociodemographic groups: The groups of people who have benefitted from the non-academic impacts and are identified in the ICS.

[8] 2015. Hanney, S.R., Castle-Clarke, S., Grant, J. et al. How long does biomedical research take? Studying the time taken between biomedical and health research and its translation into products, policy, and practice. Health Research Policy and Systems 13(1). https://doi.org/10.1186/1478-4505-13-1.

[9] 2020. Williams, K. Playing the Fields: Theorizing Research Impact and Its Assessment. Research Evaluation, 29(2), 191-202. www.doi.org/10.1093/reseval/rvaa001.

[10] 2021, Williams, K & Lewis, J. Understanding, Measuring, and Encouraging Public Policy Research Impact, Australian Journal Of Public Administration, 80(3), 554-564. www.doi.org/10.1111/1467-8500.12506.

Annex 3: Data supplementary to overview

Supplement to Table 7: Impact Types: Number of mentions

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
Total ICS	12	24	17	44	35	31	64	25	24	36	30
Changing policy and governance											
Advance policy debate	1	1	1	10	4	15	1	9	1	2	0
Inform government policy	7	1	1	25	7	17	12	6	0	1	1
Change policymakers' attitudes, behaviours or knowledge	4	2	1	18	6	6	0	0	0	0	2
End to policy	0	0	0	0	1	2	0	0	0	0	0
Changing processes and practices											
Inform procedure, practice or protocol	7	6	10	19	20	17	41	18	17	14	10
Improve workflows	0	0	0	4	10	0	5	0	13	9	12
Inform guidelines or strategy	1	6	1	14	18	4	26	5	5	8	5
Change practitioner's attitudes, behaviours or knowledge	2	18	3	26	26	7	6	2	5	0	10
End to procedure, practice or protocol	1	0	0	0	0	0	0	0	0	0	0
Service or product in regular use	1	10	2	25	14	1	4	2	18	1	18

Supplement to Table 7: Impact Types: Number of mentions (continued)

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
Total ICS	12	24	17	44	35	31	64	25	24	36	30
Changing public debate and perceptions											
Change public attitudes, behaviours or knowledge	8	20	6	23	7	15	9	4	6	1	4
Economic changes											
Commercial/financial impact	3	0	0	0	0	0	4	0	0	0	0
Commercial license agreements	0	1	0	0	1	1	12	3	1	5	7
Commercialise new technology	0	1	0	2	1	0	12	2	9	2	21
Generate profit/revenue or cost savings	1	2	0	2	11	0	7	3	9	4	21
Investment received from industry	0	2	2	5	1	1	10	0	7	7	18
Job generation	0	0	0	2	2	0	13	2	2	6	12
Open licencing policy	0	0	0	0	0	0	0	0	1	1	0
Patent	0	1	0	0	1	0	17	4	3	11	15
Profits from royalty payments	0	0	0	0	1	0	2	0	0	1	0
Spin out company/joint ventures	0	7	0	4	2	0	12	3	6	8	18
Enabling innovation in sector	1	8	2	3	6	1	2	0	6	1	11
Other	2	0	0	0	1	0	0	0	1	0	0

Supplement to Table 8: Research impact mechanism: Number of mentions

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
Total ICS	12	24	17	44	35	31	64	25	24	36	30
Co-production & collaboration											
Partnerships	1	2	0	6	3	1	0	0	8	0	1
Academic - industry partnership	1	1	0	2	12	3	13	3	11	13	18
Academic - public sector partnership	1	2	5	20	7	4	9	3	4	3	1
Academic - third sector partnership	0	1	0	11	5	3	1	2	2	1	3
Cross sector project partnership	0	1	0	7	2	0	0	0	2	1	0
Domestic partnership	0	0	0	0	0	0	0	0	0	0	0
Domestic (mainland) partnership	2	2	0	6	3	1	1	0	2	0	2
Hong Kong, Macao/Macau and Guangdong Province	1	1	0	3	5	0	0	0	1	0	0
Other parts of mainland China	0	0	0	4	3	0	0	0	1	0	7
Not specified	0	0	0	0	0	0	0	0	0	0	0
International partnership	0	7	0	6	4	1	0	0	2	0	2
Researcher Involvement											
Collaboration with sector	5	11	2	14	7	3	5	1	13	0	6
Co-produced new technology/product	0	1	1	6	2	0	4	0	9	1	6
Published output adopted by sector	0	1	0	17	7	1	0	0	6	1	1
Published output cited by sector	0	2	0	13	12	4	2	1	2	1	1
Referenced as expert, practitioner or adviser	2	7	5	19	22	14	13	6	7	6	12

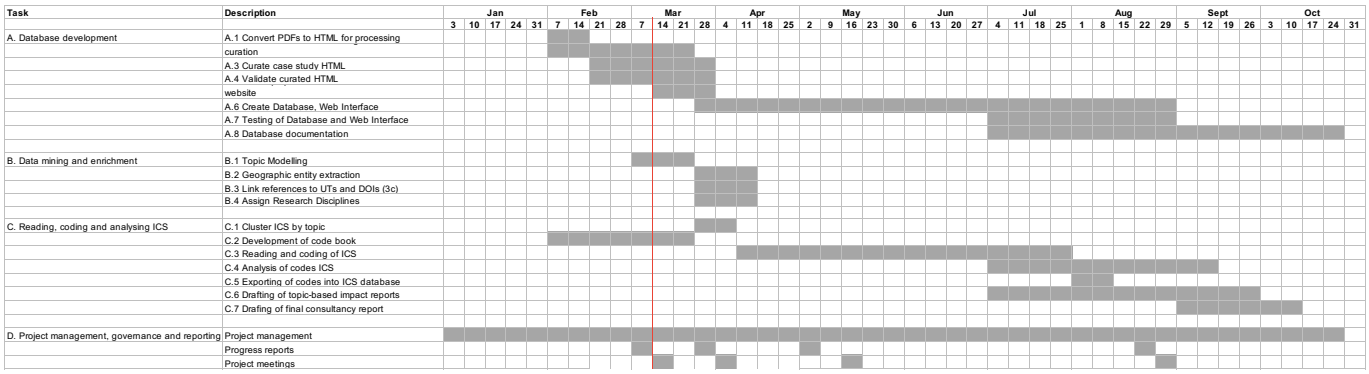
Supplement to Table 8: Research impact mechanism: Number of mentions (continued)

	Heritage & Tourism	Art & Culture	Chinese Language, Translation & Interpretation	Education & Community Services	Business & Commerce	Public & Social Policy	Health & Healthcare	Environment & Conservation	Information Technology	Engineering, Energy & Construction	Production & Technology Transfer
Total ICS	12	24	17	44	35	31	64	25	24	36	30
Disseminating research findings											
Academic presentation	1	1	1	3	2	0	1	0	4	0	0
Academic publishing	3	3	1	7	9	2	1	0	3	0	3
Educational and training materials	6	8	13	29	12	4	23	11	1	1	2
Media coverage	10	19	10	23	20	21	23	12	7	7	11
Non-academic presentation (incl public lecture)	5	17	8	20	16	18	14	8	7	5	5
Event and exhibitions	0	14	1	14	15	4	2	5	2	1	3
Open-source data website and databases	0	9	3	9	4	0	11	4	9	2	1
Publishing for non-academic audience	4	7	5	11	16	8	12	2	1	2	2
Sharing data	0	2	0	3	5	0	0	2	5	0	2
Other	7	2	1	2	1	2	3	0	0	0	0
Codification											
Prizes and awards	0	12	6	12	6	3	16	11	13	16	18
Idea/product patented	0	0	0	0	0	0	21	4	0	10	1
Idea/product/service trademarked	0	0	0	0	0	0	3	2	0	0	0
Idea/product/invention registered	0	0	0	0	0	0	2	0	2	3	0
Idea/product/invention formally recommended by recognised body	1	8	0	12	7	0	1	0	2	7	3

Annex 4: Methodology

Our approach to the study

The study was partitioned into three main tasks (Task A to C) with a project management, governance and reporting activity. In this section we provide task by task break down of how we propose to deliver on the three core objectives identified by the UGC. This annex provides details on how the project was implemented and its associated governance and reporting. In Table A.1, the shaded boxes map the tasks against the UGC deliverables.



A: Database development

Task A turned the original Impact Case Study PDF documents into a richly annotated structured dataset that could then be accessed for analytical purposes, through a web site. Although submissions were made via a standard template, the PDF documents collected were not in a structured, machine-readable format. This constrains standardised display, such as via a web interface, and inhibits the analytical potential of the data because complex queries, annotations, and links to external resources are not possible.

Hence, a significant portion of this Task is the conversion of the original PDFs into a standardised HTML format such that they can be uniformly displayed on a website, delivered as data via the database, and used in Tasks B and C for analytical purposes.

Task A.1. Convert PDFs to HTML for processing

The original 342 PDF documents were converted into a HTML representation suitable for manual curation. Open-source libraries are available but do not produce the high-quality results necessary for creation of the database because of subtle variations in how the submission template is interpreted (e.g., variant headings), the range of text formatting options (e.g. bullet lists, enumerations and tables), and the inclusion of graphs, mathematical formulas, chemical symbols, and images. This means that the automatically generated HTML will not be suitable for direct use. Multiple libraries were tested in this phase to determine which produced the best outcomes for the case study data supplied, and some automatic clean-up procedures were developed to alleviate curation burden (e.g. removal of extra whitespace and normalisation of HTML tags emitted).

Task A.2 ad A.3. Manual curation

A manual curation team were used to produce high-quality, uniform HTML documents and shared training materials were developed to maximise consistency of processing:

- Small alterations to standardise document structure and ensure the five primary sections of the template are properly separated and labelled;
- Text formatting situations such as lists and tables;
- Capturing and embedding images in the HTML;
- Codifying mathematical equations, chemical symbols, and other domain specific syntax.

The curation team also extracted structured data relating to literature referenced in the References to the research section of each ICS document, extracted the text of bibliographic references and captured Document Object Identifiers (DOIs) and year of publication.

Unforeseen situations were encountered, necessitating updates to documentation and additional training. PDFs with difficult and unique layout scenarios were held back to review at the end after more experience had been acquired. Additional checks were made to ensure proper rendering of Chinese characters.

Task A.4. Validate curated HTML

After sanitising the HTML versions of the original ICS PDFs, additional validation was performed to ensure high-quality data. This involves manual inspection of the output HTML files, as well as automated tests (e.g., check all five ICS sections are present, proper reference capture). Some documents that did not pass validation were re-processed.

Task A.5. Develop specification for database and website

During the development of the UK REF2014 Impact Case Study database, a user-experience-led design process was followed to determine how the public website should work. Part of this process involved interviews with relevant stakeholders including research offices, funders, academics and governmental departments to determine the ideal functionality of the database. Through these interviews, various functional and non-functional requirements were identified with respect to searching, data modelling and presentation. Reference to this work was made again here, since the intended UGC functionality is well aligned with that of the UK database.

The specification included:

- Faceted browsing – users able to will browse the data according to different facets, such as the submitting institution, unit of assessment or type of impact.
- Search – users able to search ICS text using powerful query operators, for example to search for terms near to others, via logical operators (e.g. AND, OR), compound phrases, and with wildcard characters (including the option to search within subsections of the case studies, for example, to search in "Section 4 Details of the impact" for specific beneficiary groups.
- Data Model – The way in which information about the ICS is structured is relevant to the design of database and how records are displayed. A number of additional metadata fields were created and associated with the ICS, through either automated techniques (Tasks B.1 Topic Modelling, B.2 Geographic entity extraction, B.3 Link references to UTs and DOIs, and B.4 Assign Research Disciplines), or via manual tagging (Task C.3).

Task A.6. Create Database and Web Interface

The database and website were delivered to client technical requirements relating to hosting and technology stack.

Curated HTML for each ICS were integrated with additional metadata generated by topic modelling (Task B.1), geographic entity extraction (Task B.2), DOI linking (see Task B.3), research discipline assignment (Task B.4), and case study codification (Task C.3) and loaded into an appropriate data model to serve content via the website. This can be either through the web interface, designed for users to search and explore the data interactively.

Task A.7. Testing of Database and Web Interface

Tests were implemented as part of the development methodology, with appropriate tests created for each feature to pass before acceptance by the product owner.

At the end of the project, further user testing was performed by the wider team to verify the website and database function properly, as well as demonstration sessions for the UGC.

Task A.8. Database documentation

After the database has been successfully implemented, documentation will be created that explains the technical design, including database schemas, tests used, and codebase structure. Instructions on how to deploy the database on the desired technology will also be provided. This documentation will allow the customer to make future changes to the database, for example to change branding, remove individual records, add metadata fields, or otherwise modify the application.

B: Data mining and enrichment

The aim of this task is to supplement the case study data with additional information that can be extracted from the text using data mining and machine learning techniques. This will greatly enhance the analytical potential of the data as it will allow analysts to identify and group case studies according to a range of additional categorisation schemas and link to bibliometric data for cited research.

Task B.1. Topic Modelling

Topic modelling is a language processing technique that can be applied to document sets to understand the different combinations of words or phrases (topics) that are present. It is a data driven approach, meaning results are not dependent on pre-conceived notions of structure, but are instead derived from the data itself.

In our prior analysis of the REF2014 impact case studies, topic modelling proved to be an effective tool in understanding the makeup of case studies in terms of beneficiary groups, pathways to impact, and relevant policy issues. Generating topic models on different sub-sections of case studies is especially useful as it can yield different insights. For example, using the text from only Section 1 Summary of the impact provides a good impression of the overall domain of impact, but using text from Section 4 *Details of the impact* will surface more subtle aspect relating to beneficiary groups, locations and impact types.

Topic modelling requires the analyst to specify the number of desired topics. If this is set to be small (e.g., 5-10), only broad and general groupings will be discovered. As the number is increased (e.g., 25 or 50), more granular topics will be derived, until the number of topics is so high that duplicate topics emerge and artifacts begin to appear (i.e. topics only relating to textual features of the document such as common journal names cited in references). Our experience is that multiple models should be generated and manually reviewed by domain experts in order to determine a suitable and useful number of topics.

Python, Scikit Learn, and Gensim packages were used in this instance to implement the topic modelling. ICS text was normalized (i.e., removal of punctuation and diacritic characters), and domain specific stop-words (words used frequently that don't discern documents from one another) were removed (including words appearing in > 50% documents).

Task B.2. Geographic entity extraction

One aspect of the impact case studies that is of relevance to analysts and policy makers is where impact took place. Typically, this is described in the case study text, so recognition of geographic entities mentioned provides additional benefits to the user. Further, by identifying in which of the five major sections any locations are mentioned, users can home in on potential impact regions, for example by limiting searches to only Section 4 Details of the impact.

The open-source Edinburgh Geoparser[11] was used to mine ICS text for mentions of locations. The Edinburgh Geoparser is a system to automatically recognise place names in text and disambiguate them with respect to a gazetteer. For the purposes of this analysis, the open-source Geonames[12] gazetteer was used as it provides global coverage and contains an extensive list of place names. Manual verification ensured common errors were not propagated to the database: it is impossible to automatically determine all correct locations due to common and ambiguous place names. Geographic locations were linked to ICS using open-source identifiers which will enable analysts to easily reuse the data for mapping and geospatial tasks without the need for additional data licenses.

Task B.3. Link references to UTs and DOIs

In each ICS, Section 3 *References to the research* contains up to six citations to academic literature, usually journal articles or books. By linking ICS data to the associated works, bibliometric analysis can be performed, providing additional analytical options.

During the curation process (Task A.3), these references were identified and extracted from the text and DOIs mentioned in the text were associated with these references to optimise links to bibliographic databases. References without DOIs were run through the Clarivate record matching service to obtain the correct DOI.

Task B.4. Assign Research Disciplines

Although ICS are submitted under research areas according to their Unit of Assessment, it is beneficial to associate each ICS with more granular research classifications to aid analysis, for example to distinguish research in sub disciplines (e.g., organic versus inorganic chemistry), or help to identify interdisciplinary research.

Web of Science™ journal categories for research publications matched in section three of the case studies were collected. The top six most frequently assigned categories were assigned to the case study. In a small number of cases, more than six categories with an equal weight were found - in this situation, manual review determined the best six categories to use based on providing the broadest coverage of subjects and disciplines.

[11] www.ltg.ed.ac.uk/SOFTWARE/GEOPARSER
[12] www.geonames.org

Task C: Reading, coding and analysing ICS

All the 342 ICS were read to identify and code salient features that would allow for cross-case analysis and become the basis of synthesised impact reports. The task employed the topic modelling and directed content analysis in a sequential multi-method approach.

Topic modelling (Task B.1) identified ICS topics by using underlying data rather than researcher assumptions. Qualitative directed content analysis then elucidated the central characteristics of the impact narratives. This involved an iterative process of examining case studies and the development of a code book to categorise salient features, allowing patterns between the codes to be described in synthesised impact reports.

Task C.1. Cluster of the ICS by topic

Exploratory topic modelling (Task B.1) identified ICS clusters with results refined through discussion with the UGC. UGC and the team developed an initial topic taxonomy to inform the coding and testing of case studies, drawing on existing literature and material generated from the UK REF2014 analysis as well as an initial analysis undertaken by reading the UGC ICS summaries. Grouping by topic at the outset ensures that ICS were read and analysed in batches that were cognitively similar, which enhances the coding and analysis and thereby strengthens the impact reports.

Task C.2. Development of code book

The code book was derived from the existing literature and the domain expertise of the authors. It included four overarching categories: a) research, which captured funding source and impetus for research; b) time lags, which captured the elapsed time between the research and its impact; c) mechanisms/channels of impact, which included forms of collaboration and dissemination; and d) impact, which included beneficiary groups (e.g. young people, women, ethnic minorities), location and reach (e.g. Hong Kong, Mainland China, elsewhere), and the nature of impact (e.g., commercial, policy, practice).

Task C.3. Reading and coding the ICS

Using the cloud based qualitative analysis software, Dedoose, each case study was read, and relevant excerpts were 'tagged' with the relevant codes. Multiple codes and subcodes were attributed to individual case studies. This allowed all case studies that had been tagged with a particular code (e.g., a particular beneficiary group) to be considered as a group. Two of the study's authors undertook the reading and coding. Inter coder reliability was ensured by double coding 10% of the cases (i.e., each author codes the same case study) and through regular coding meetings that were used to compare code applications and adjust the code book as required. The code book was thus a 'living document' that was reviewed and revised iteratively. This process allowed for cross case analysis that was the basis of synthesised impact reports. The properties of the ICS were systematically examined, and evidence was gathered by assigning segments of text to unique codes within the broader coding categories.

A small number of case studies could not be matched to an impact topic and these were read and coded last to enable either topic assignment through experiential familiarity rather than modelling algorithms or the identification of stand-alone cases.

Task C.4. Analysis of the coded ICS

Cross-case analysis drew out similarities and differences between each of the topics identified and ICS clusters created. A standard set of visualisations was developed to support reference and reporting materials.

Task C.5. Exporting of codes into ICS database

Relevant codes can be exported and incorporated into the ICS database (Task B) to facilitate advanced searches. For example, this enables a search on beneficiary groups (e.g., teachers, farmers, children) which is an innovation not feasible for the UK REF2014 ICS since such groups could not be specified through automated text mining. However, reading and coding each UGC ICS does extract such information.

Task C.6. Drafting of topic-based impact reports

A short impact report was generated for each substantive topic to evidence the societal, economic and technological impact of Hong Kong research. Each report is based on the cross-case analysis (Task C.4) but written to enhance its role as a more accessible information source. The narrative of each report draws on and cites specific examples of impact, with full representation across the eight UGC-funded universities.

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