AUTUMN 2018 | Issue 9

Institute for Manufacturing REVIEW

Collaborations that make a difference...

- A new world-leading asset arrives in Cambridge
- The joint effort to reconfigure pharmaceuticals manufacturing
- Ecosystem mapping for London underground
- Bringing companies together for open innovation
- Celebrating an EPD award for an outstanding partnership

UNIVERSITY OF CAMBRIDGE
Department of Engineering

IfM | MANAGEMENT TECHNOLOGY POLICY

INSTITUTE FOR MANUFACTURING (IfM)

The IfM is part of the University of Cambridge's Department of Engineering. With a focus on manufacturing industries, the IfM creates, develops and deploys new insights into management, technology and policy. We strive to be the partner of choice for businesses and policy-makers, as they enhance manufacturing processes, systems and supply chains to deliver sustainable economic growth through productivity and innovation.

IfM EDUCATION & CONSULTANCY SERVICES LIMITED (IfM ECS)

IfM ECS is owned by the University of Cambridge. It transfers to industry the new ideas and approaches developed by researchers at the IfM. Its profits are gifted to the University to fund future research activities.

Cover: Image by Dr Etienne Rognin, © Institute for Manufacturing, University of Cambridge
The image shows a polymer molecule stretched and unfolded in a strong fluid flow imparting substantial mechanical tension (coloured in red) along the backbone. The science underpinning manufacturing flows can allow us to turn newly reported mechanochemistry and molecular design into a revolutionary and scalable process.

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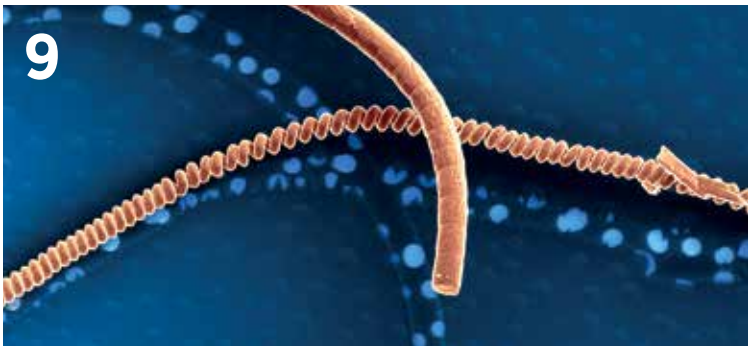

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www.ifm.eng.cam.ac.uk/research/ifm-review

Collaborating to make a difference

Welcome to Issue 9 of *IfM Review*. In this issue we highlight a selection of recent IfM projects, many of which are united by a common thread: the value of collaboration.

From its inception, the IfM has been active in building collaborations and networks. In everything we do, we seek opportunities to share ideas and to access the expertise of colleagues with different interests in order to help us address the most pressing problems facing manufacturing today and tomorrow.

The IfM building (celebrating the tenth anniversary of its opening next year) was designed with the Common Room at its heart, a place for meetings, chats and gatherings, where ideas can be exchanged over coffee. Our renowned 'Bun Talks' every Friday morning continue to provide a chance to hear updates on the work and ideas of people around the organisation and beyond - followed by buns and networking.

We highly value our external networks and collaborations, and actively encourage efforts to connect with fellow researchers from across the University and beyond, and we forge wider partnerships with government and industry. Our new affiliation with EEF is one such example, as is our continued knowledge transfer activity through IfM's Education and Consultancy Services' work with industry. Also in this vein, Dr Eoin O'Sullivan and the Policy Links Unit are bringing together influential policy makers to share and discuss approaches to shaping manufacturing policy, as illustrated by the convening of a recent roundtable with the WEF, OECD and the UN (page 6).

Along the theme of collaboration, Dr Ronan Daly describes the recent acquisition of Orion NanoFab, an exceptionally sophisticated microscope which will provide researchers with a capability to achieve strides forward in their work (page 9). The potential value of bringing this powerful resource to Cambridge galvanised a collective effort from 50 research groups across 10 departments as well as other universities and industry groups. Ronan explains why Orion NanoFab has stimulated support from such a large network, and why IfM has been driving the bid.

Another major collaboration is explored on page 12: ReMediES has been an impressive £23m four-year project to remodel the UK's pharmaceutical supply chain involving 22 industry partners and two leading UK universities. Dr Jag Srai, who was involved in shaping the project from the beginning as Research Director, provides insights into some of the key achievements, including the benefits of introducing a collaborative model into a highly competitive industry.

Collaboration also features as a theme in a piece on the work of the Open Innovation Forum with Dominic Oughton (page 23), highlighting work with industry partners in the food and drink sector. Professor Duncan McFarlane provides an overview of the 'Digital Manufacturing on a Shoestring' project, working with a range of SMEs and partner organisations on low-cost digital solutions (page 18). And we explore the importance of ecosystem relationships (page 26), in an article on ecosystem mapping with Dr Florian Urmetzer: this case study on Transport for London reveals how value exchanges can be identified and developed for mutual benefit between ecosystem members. Connections between research and practice are further emphasised in a piece on intellectual property by Dr Frank Tietze (page 30).

The success of one of our long-standing collaborations has been recognised through the success of the IfM's Executive & Professional Development (EPD) team winning the prestigious 2018 EFMD Excellence in Practice Silver Award for its Learning and Development partnership with Atos and Paderborn University (page 16). We also hear more from Dr Judith Shawcross, Head of EPD, in an article about the challenges of describing skills relating to student industrial placements (page 20), a thought-provoking piece as we welcome a new intake of undergraduates and MPhil students to the IfM.

We hope you enjoy this issue. As always, we welcome your thoughts and comments, and we look forward to hearing from you to help us build future collaborations.

Best wishes,

Tim Minshall
Dr John C Taylor Professor of Innovation, & Head of the Institute for Manufacturing

IfM news

Manufacturing a better world: IfM hosts vibrant 2018 Briefing Day

Leaders and senior executives from industry, government and academia gathered together for a lively and thought-provoking annual Briefing Day at the Institute for Manufacturing (IfM) on 17th May.

The event provided an opportunity for delegates to hear about cutting-edge manufacturing research from leading academics at the IfM, as well as to engage with discussion workshops, practical activities, and demonstrations of new tools and technologies to address business challenges.

'Manufacturing a better world'

The opening address by Professor Tim Minshall, Head of the IfM, set out the conference theme of 'Manufacturing a Better World' and why this has been adopted as the IfM's vision. He talked about 'big M-manufacturing' in its broadest sense, placing manufacturing at the heart of solving many future global challenges.

This was followed by fascinating talks by leading IfM academics around three cross-cutting areas of research at the IfM: digital, healthcare and skills. Professor Duncan McFarlane provided an overview of the IfM's approach to understanding digital developments in manufacturing, setting digital technologies into context and emphasising that new technologies only make sense if they are addressing a problem rather than becoming an end in themselves.

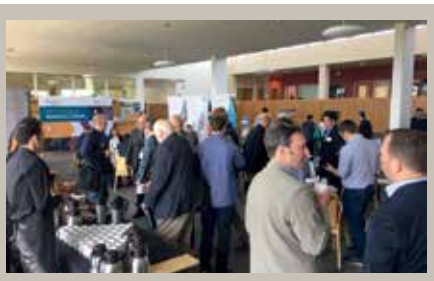
Dr Jag Srai presented recent work in the area of digital supply chains, with an overview of the ground-breaking project ReMediES, involving IfM's collaboration with GlaxoSmithKline, AstraZeneca and 20 other organisations to reimagine the pharmaceutical supply chain.

An overview of research in additive manufacturing was provided by Professor Bill O'Neill, with example applications in healthcare including significant improvements to implants which have had life-changing effects for patients.

Professor Tim Minshall then explored the significance of skills and people for the future of manufacturing, with particular consideration given to how we might adopt a lifelong learning approach to equip the current and future workforce to address future (as yet probably unknown) challenges and technologies.

Panellists discuss the future of manufacturing

A panel discussion enabled delegates to raise some penetrating questions around the theme of 'Manufacturing a Better World'. The panel featured representatives from government, business and academia: Clare Porter, Head of Manufacturing from the Department for Business, Energy and Industrial Strategy, Jon-Paul Sherlock from



AstraZeneca, and Professor Andy Neely and Professor Steve Evans.

Asked whether they would encourage children into manufacturing, the panellists all gave a confident and reassuring "Yes!" followed by some interesting thoughts on how outreach programmes into schools could be made more effective. There was a call for a more coherent approach to outreach work, and perhaps a need for more lively input from younger representatives of engineering, including highlighting entrepreneurial opportunities.

Other questions prompted discussion about the role of artificial intelligence in R&D, intellectual property issues in the sectors of food and healthcare, and what the manufacturing landscape might look like in 10-20 years.

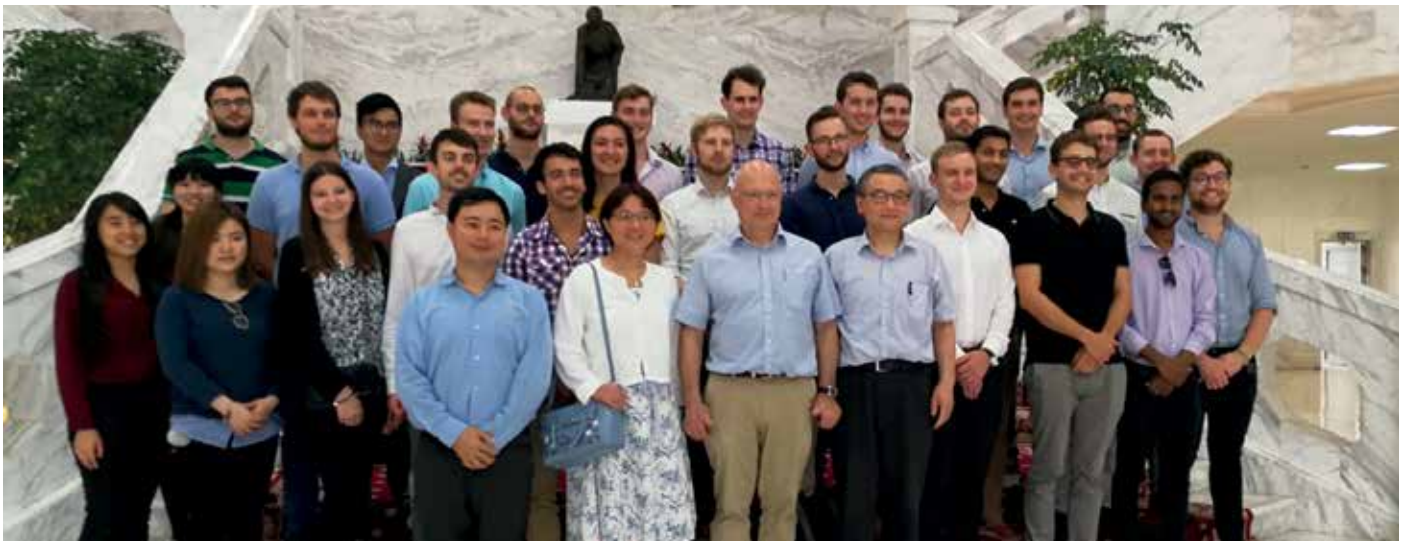
Taking new ideas home

After networking over lunchtime, delegates had the opportunity to select a choice of workshops, with topics including skills, policy developments, medicines manufacturing, service strategy, and innovating for sustainable value.

There was also a chance to take part in an interactive tour of digital manufacturing at the IfM, showing how digital technologies are changing the way manufacturers do business. This included a demonstration of a virtual reality robot lab, virtual maps of supply chains, asset management solutions, and inkjet printing.

Feedback was very positive from attendees, who reflected on a constructive day packed full of valuable ideas and new insights. We look forward to welcoming attendees again for the 2019 Briefing Day, as well as to other membership and open events in the meantime.

IfM news



ISMM study tours 2018

A valued feature of the IfM's MPhil in Industrial Systems, Manufacture and Management (ISMM) is that students have the opportunity to take part in a study tour, to gain insights into issues and industry challenges in a different country or sector.

In 2018, one group headed to Germany to explore the future of mobility, including driverless cars, electrification and vehicle sharing. The students visited a total of 7 cities and had 15 official engagements. Throughout the tour, the ISMM group questioned the host companies on their visions for the future of mobility and critically analysed the information presented to them.

Another group visited Taiwan and South Korea. To understand the challenges these economies are now facing, this year's international study tour focused on industrial sustainability, Industry 4.0 and marketing, and included over 25 companies. The visits covered a broad spectrum of industries, from artisanal craft paper producer Andong Hanji to world-leading semiconductor manufacturers such as SK Hynix.

MET Design Show 2018

Excellent, inventive product prototypes went on display from our Manufacturing Engineering Tripos (MET) undergraduates on 6th June. This is a major examinable component of the 3rd year course, for which students develop a new product with real business potential. They are asked to identify a customer need, research the market, develop original design concepts and create a full business plan. In previous years, a number of prototypes have gone into commercial production and won national prizes.

This year's projects included Soap for Life, providing cheap and sustainable access to soap for rural communities facing hygiene issues by creating anti-bacterial soap from by-product ash and cooking oil (by students Josh Shemtob, George Barbantan and Phil Knott); and Hyperbot Pro, an autonomous buddy designed to capture hyperlapse footage, with an interface that can be integrated with a smartphone application for effective videographic creations (by Tom Wilson, Miran Gilmore and Josh Thomson).

There were eight other excellent projects: Autobatik, The Bluebox Skipper, Hexamill, Garbage Guardian, Leaflogger, The Muracle, Paper Mill Thrill and ReadySteadyGyro. Read more about all the 2018 Design Show projects at www.ifm.eng.cam.ac.uk/education/met/design

‘How stuff gets made’

Children in local primary schools around Cambridge have been learning more about ‘How Stuff Gets Made’ thanks to a programme being delivered by IfM and Engineering students and researchers with the Faculty of Education.

Activity days were hosted with Year 5 pupils at Arbury, Cottenham, Queen Emma and Fulbourn Primary Schools, and St. Mary’s Junior School. The IfM team, led by PhD student Susannah Evans, designed engaging activities to introduce manufacturing concepts to children, and worked with teachers to tie these in with the curriculum of each school. The University’s Faculty of Education provided valuable advice and guidance to ensure that the activities aligned with the needs of schools.

Pupils enthusiastically tackled a variety of challenges, including designing and making boats and paper aeroplanes, learning about buoyancy and aerodynamics. They also made devices to carry ping pong balls down a zip wire in the quickest possible time.

The outreach programme was awarded funding by the Royal Academy of Engineering’s *Ingenious* grant scheme, with additional funding provided by the Sharman family and Churchill College.

Joining the World Open Innovation Conference

Dr Serena Flammini has been appointed as Assistant Program Chair of the World Open Innovation Conference, joining the organising team of the event. The Conference combines the latest research and management practices on Open Innovation. The specific focus of this year’s event, on 13-14 December 2018 in San Francisco, will be “Digital Transformation for Sustainability”.

CIS’s Dr Curie Park wins Newton Fund Institutional Grant

Dr Curie Park from the IfM’s Centre for Industrial Sustainability (CIS) has won the Newton Fund Institutional Grants (delivered by British Council) to conduct a one-year research project in Thailand.

For this interdisciplinary waste innovation project, CIS is partnering with Thammasat University to build local innovation capacity among the local students, SMEs, NGOs and Thai Creative Design Centre.

The research activities include experimenting with local industrial waste to identify high value innovation opportunities, and designing sustainable business models for the local entrepreneurs.

A milestone was successfully completed in August, with the Experimentation Phase attracting 100 delegates to its final showcase event at the Thai partner university on 15th August. The focus of this phase was on creating high value innovation ideas through experimenting with industrial waste.

Game changers under 30

Congratulations to Wen Liu, Doctoral Researcher in CIS who has made this year’s Forbes 30 Under 30 Asia List of “game changers under 30 transforming the world”. He is the co-founder of Illume Research, an education technology company that focuses on cultivating students’ research abilities and innovation capabilities, through providing custom-made cutting edge research programmes, teaching management systems and online education platforms.

IfM news

We bid a fond farewell to Tom Ridgman, retiring this year. Tom has been a stalwart of the IfM since 1995. He joined us as Course Director for our highly respected one-year postgraduate course, overseeing its transition to the MPhil in Industrial Systems, Manufacture and Management (ISMM). As Director of External Education he has developed a range of courses for industry, and he has also been a key member of the Manufacturing Industry Education Research Group. We wish him all the best for the future.

Congratulations to former Head of the IfM, Professor Andy Neely, Pro-Vice-Chancellor for Enterprise and Business, University of Cambridge, who has been elected to a Fellowship of the Royal Academy of Engineering.

Congratulations to Dr Letizia Mortara, appointed as University Lecturer in Technology Management earlier this year.

Also we congratulate Dr Veronica Martinez, appointed as University Lecturer in Services and Sustainability in July 2018.

We welcome Dr Sebastian Pattinson, new University Lecturer in Manufacturing Processes, Systems and Organisations, who joined the IfM in September 2018.

The future of manufacturing futures

On 16th July, IfM's Centre for Science, Technology and Innovation Policy (CSTI), together with the Policy Links Unit and the Babbage International Policy Forum, hosted a roundtable event for manufacturing foresight practitioners and policy analysts from leading multilateral organisations and international bodies.

Participants included representatives from the Organisation for Economic Co-operation and Development (OECD), United Nations Industrial Development Organisation (UNIDO), the World Economic Forum (WEF), the United Nations Conference on Trade and Development (UNCTAD), as well as the UK government.

The event was designed as a unique opportunity for experts from the different organisations to share insights, perspectives and analyses about the future of production; and reflect on the implications of industrial strategies and national policies on manufacturing and innovation.

In particular, the roundtable event offered participants the opportunity to compare and contrast their different initiatives and findings, and share effective practices and lessons learned from their respective initiatives, as well as to explore common methodological challenges related to manufacturing foresight and policy analysis.

Themes addressed at the roundtable included:

- The impact of emerging technologies on global value chains and production systems;
- The acceleration of technological innovation for inclusive globalisation, sustained competitive advantage, and environmental sustainability;
- The role of institutions for technology generation, diffusion and deployment; and
- Challenges for small and medium enterprises to stay relevant in future value chains.

CSTI and Policy Links were ideally placed to facilitate discussion, having worked recently with the international organisations involved and identified common interests. There was a clear opportunity to bring together a community of practitioners and provide an opportunity to share ideas and experiences.

The event was also supported by the Babbage International Policy Forum, with former Head of the IfM, Professor Sir Mike Gregory, chairing the opening session and hosting a dinner at Madingley Hall, which provided an ideal location for this type of international expert roundtable meeting.

IfM news

Advancing policymakers' understanding of regional innovation funding

The Centre for Science, Technology and Innovation Policy (CSTI) hosted a roundtable on 9th July 2018 bringing together academic experts with senior policy officials to explore academic evidence and translate it into practical implications for 'place-based' funding programmes.

Place-based approaches to policy are based on the argument that, to be effective, public interventions need to be place-specific and address the particular needs, opportunities and challenges of the local area, whether they be towns, cities, or regions. In the context of research and innovation funding programmes delivered by UK Research and Innovation (UKRI), such an approach would mark a significant deviation from a traditional focus on funding excellence wherever it is located nationally.

The Cambridge roundtable discussion provided an opportunity for leaders from UKRI and the Department of Business, Energy and Industrial Strategy to explore together the rationale for investing in local research and innovation systems to deliver local economic benefits. The aim was to inform UKRI's long-term thinking around how it can play an active role in delivering the UK government's industrial strategy and, in particular, the place-based agenda to reduce regional disparities in productivity.

Concepts, insights and evidence were provided by four leading academic experts. Adding to this, CSTI and Policy Links Unit contributed examples and insights from a review of international regional research and innovation funding programmes.

CIM Symposium

A packed programme at the IfM's 22nd Cambridge International Manufacturing Symposium, on 27-28 September 2018 in Cambridge, featured speakers including Siemens UK CEO, Juergen Maier, alongside international counterparts from a range of sectors. This year's event, hosted by Dr Jag Srai and Dr Paul Christodoulou, was themed 'Supply Chain Transformation Enabled By Advanced Technologies: Implications for Producers, Consumers and Society'.

Policy Links report for Innovate UK:
The practical impact of digital manufacturing

Innovate UK asked Policy Links and the IfM to collect and analyse evidence on potential benefits derived from the adoption of digital technologies in the manufacturing sector. The study has now been published as a report, *The Practical Impact of Digital Manufacturing: Results from Recent International Experience*.

The Made Smarter Review estimates that UK industry could achieve a 25% increase in productivity through digital adoption by 2025. However, most estimates to date have focused on the expected impact of digital adoption, primarily on the basis of macroeconomic extrapolations and survey data.

This study makes an important contribution by investigating the observed impact achieved by manufacturers around the world when deploying digital applications and solutions across their operations (with a strong focus on SMEs).

The report also reviews recent digital adoption efforts and studies in key manufacturing countries, offering strategic insights for future policies aimed at supporting digital manufacturing in the UK.

The report can be found at bit.ly/2NrApBF

IfM news

New partnership between IfM and EEF

We are pleased to announce a new partnership between IfM Education and Consultancy Services and EEF, the manufacturers' organisation. The two organisations have closely aligned objectives and shared values, both working to promote UK manufacturing organisations. As an Affiliate Partner, IfM ECS will be collaborating with EEF on a range of activities, including events, resources and member support.

IfM ECS members are entitled to complimentary affiliate membership of EEF, with access to a range of EEF resources. These include online resources, representation, and benchmarking tools.

Additional resources provided by EEF include the Problem Solving Network, an online community for discussing practical solutions to real world business challenges. IfM researchers will be contributing expertise to the forums on the network.

We hope to co-host events on topics of importance to UK manufacturers, with the ability to draw on expertise from EEF economists and IfM researchers. Working with other affiliate partners and industry organisations and the academic community, these can further strengthen networking potential and extend industry reach, adding value for members.

Both the IfM and EEF are proactively working with government bodies to provide expertise and knowledge for policy makers. Input from members of both organisations helps to inform this process, and we are keen to facilitate open discussion through events, surveys and networks.

We are also working with EEF to support academic research projects, including a current project with a research team led by the IfM's Dr Thomas Bohné. The team spent a week at EEF's Technology Training Centre in Birmingham, working with apprentices from manufacturing companies to assess the effectiveness of virtual reality and haptic gloves for learning and practising new skills. Using an experimental research approach, the apprentices were put into different groups where they learned to assemble a clutch provided by John Deere UK (see page 32).

Tim Minshall, Dr John C Taylor Professor of Innovation and Head of the IfM, commented:

"We are delighted to be cementing our long-term relationship with EEF into a formal Affiliate Partnership, providing deeper value for our members and enabling both organisations to promote UK manufacturing even more effectively through a range of collaborative activities."

Charles Garfit, EEF's Membership Engagement Director, said:

"We are very much looking forward to working more closely with IfM ECS, and welcome them as new Affiliate Partners. Our shared values and complementary strengths give us an excellent platform for coordinating our efforts to support UK manufacturers."

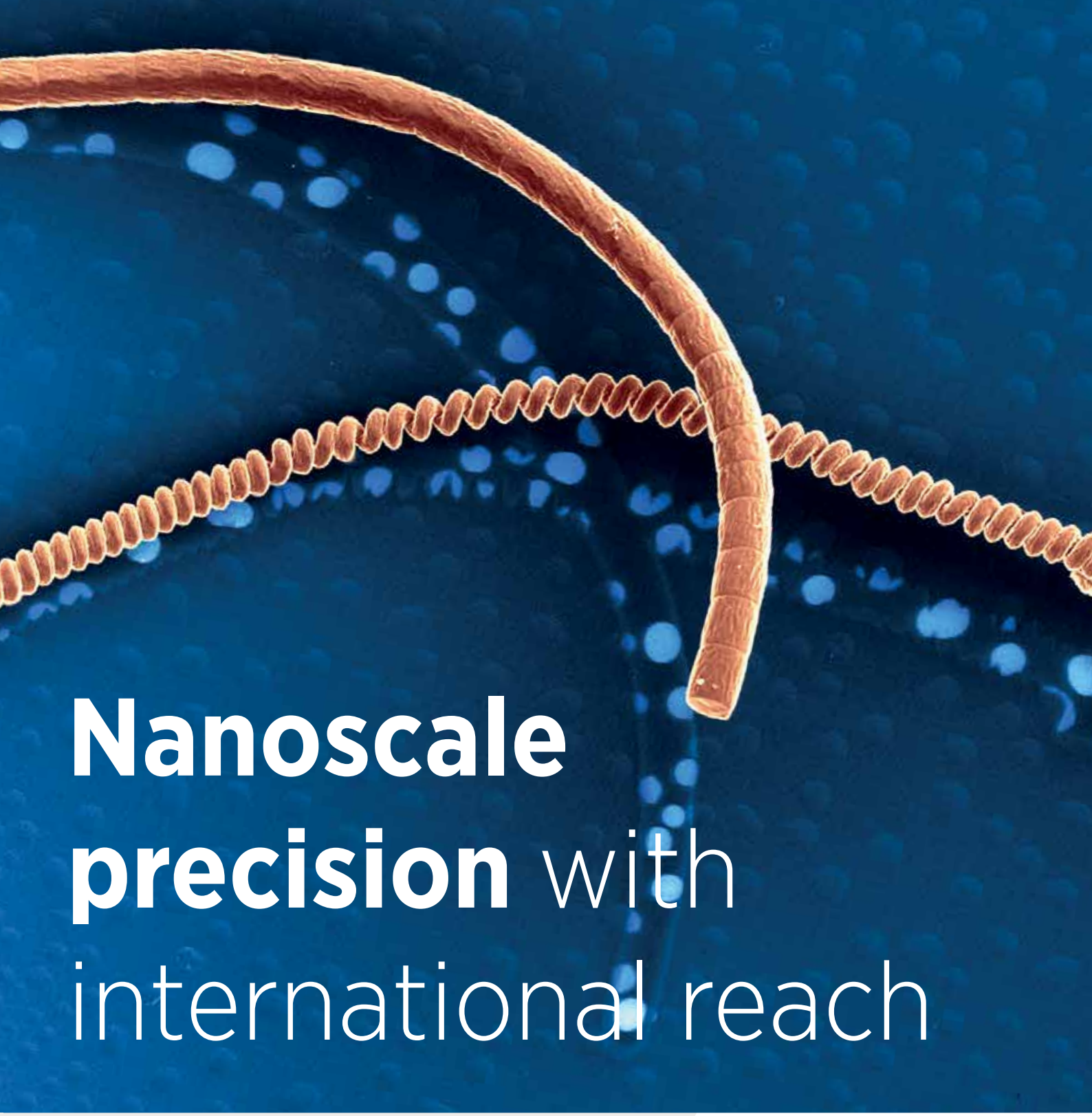
Become an IfM member

The IfM has a membership scheme for small and medium sized manufacturers, building close, long-term relationships with members including access to our wide range of expertise.

Some benefits of IfM SME membership include:

- Places for you and/or your employees on SME member training workshops.
- Opportunities to network with peers and IfM staff at social events such as the members' summer garden party, usually held in the grounds of one of the Cambridge Colleges.
- Opportunities to engage with Cambridge University undergraduate and postgraduate students on potential projects and placements.

For more information: **www.ifm.eng.cam.ac.uk/smemembership**



Nanoscale precision with international reach

Sample of cyanobacteria from Orion NanoFab, courtesy of ZEISS ©

Cambridge has acquired a powerful new capability, through the EPSRC Strategic Equipment process, with the potential to enable important advances in research across a range of disciplines. Orion NanoFab is an exceptionally sophisticated microscope made by ZEISS which will equip researchers across the University, as well as from other institutions and the private sector, with the ability to analyse and modify matter at the nanoscale with unprecedented precision. Dr Ronan Daly, Head of the Fluids in Advanced Manufacturing research group at the IfM, led the bid for its funding in a coordinated effort with colleagues from the Department of Engineering, the Cavendish Laboratory, and Cancer Research UK Cambridge Institute, and with wide support. He explains more about why this is such a valua asset for the University and beyond.

It is rare indeed that a single piece of equipment can offer the potential for substantial developments across a diverse range of research areas, to the extent that it galvanises support from a broad interest group. But such is the case with Orion NanoFab, Cambridge's newly-procured microscope with world-leading functionality, which has been funded by EPSRC under the Strategic Equipment process and newly installed in the Nanoscience building on West Site.

The significance of bringing this technology to Cambridge is underlined by the weight of support behind the funding bid.

As part of a cross-discipline team involved in the bid, I worked with Dr Stefanie Reichelt (Cancer Research UK, Cambridge Centre), Professor Bill O'Neill (IfM, Engineering), Dr Richard Langford (Physics) and Dr Raymond Wightman (Sainsbury Lab). We had influential backing from two of Cambridge's Pro-Vice-Chancellors, Professor Andy Neely and Professor Chris Abell.

The bid was supported by over 50 research leaders across the breadth of Cambridge University, researchers in an additional 4 universities, 4 EPSRC Centres for Doctoral Training, 2 Catapult organisations, and 3 industrial networks reaching 1,500 companies.

So what's special enough about a microscope to generate this level of engagement?

What is Orion NanoFab?

ZEISS has worked with us to construct this unique version of NanoFab, a state-of-the-art system for ultra-high resolution imaging, cross-sectioning, nanopatterning and analysis.

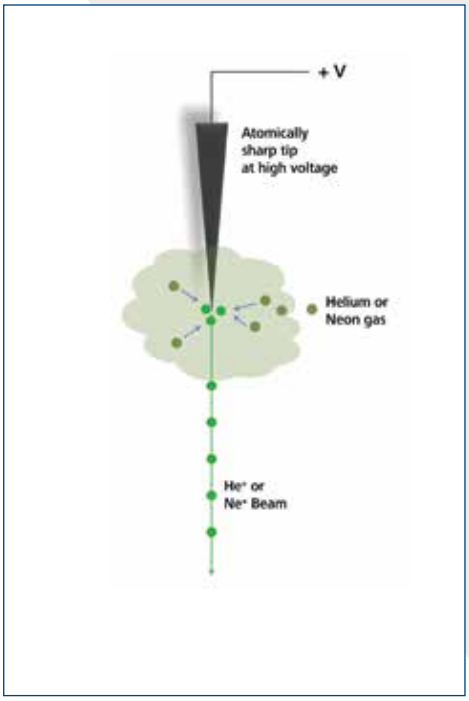
The advanced tool for metrology and machining is a customised helium, neon and gallium ion microscope with cryogenic sample capability.

This instrument is of great value to our bioengineering, nanotechnology and clinical research due to two main capabilities.

Ultra-high resolution

Firstly, the tool has a sub-0.5 nanometre image resolution. The microscope can image non-conducting materials at ultra-high resolution without a build-up of charge and with a depth of field 5-10 times higher than a conventional scanning electron microscope (SEM). The quality of imaging is further enhanced by higher integrity of specimens, achieved through advanced cryogenic handling.

One of the problems for examination of biological samples is that specimens need to have liquid water removed to be stable under the high vacuum. But drying out specimens can change how they appear under the microscope. Orion NanoFab's cryogenic handling system is revolutionary for soft matter, biological and hydrated sample imaging as it can look at samples

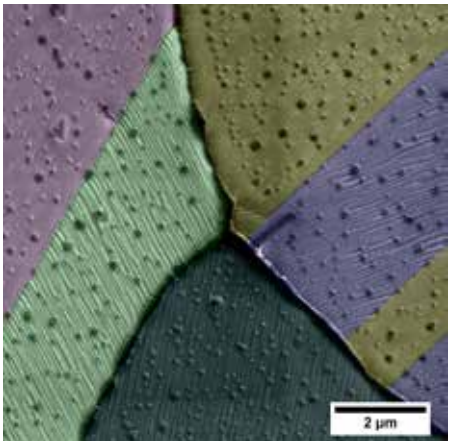


with this ion beam technology without removing water from within the structure.

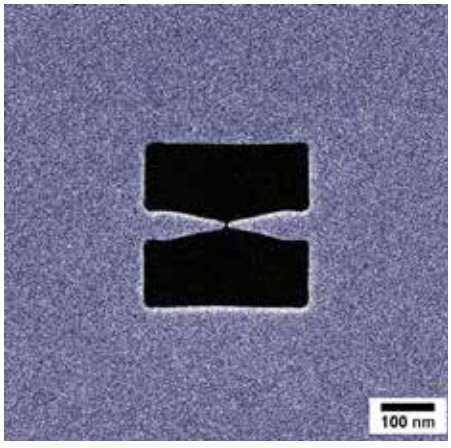
Nanoscale machining

Secondly, the three ion beams can be used together for nanopatterning with 2 nanometre resolution.

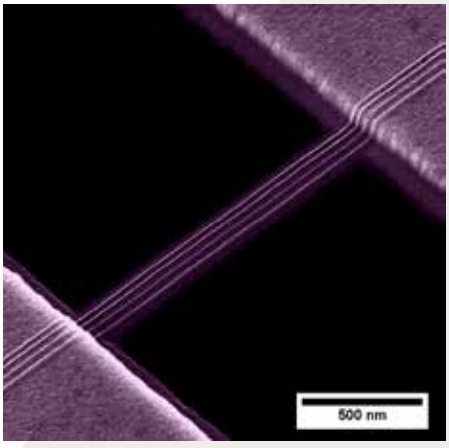
This means it can directly machine away parts of the sample or write conductive lines with incredible resolution and accuracy.



Grain boundaries



Single-step fabrication of gold antenna



Helium deposition, metal lines

To find out more about Orion NanoFab features and to access its use, please visit www.orion-nanofab.cam.ac.uk

Research boost

There are many important research projects already underway in Cambridge that will benefit from these capabilities.

Among these is work to develop implantable electronics, a field that creates tools to help understand how to diagnose and treat neurological disorders. Professor George Malliaras, the Prince Philip Professor of Technology here at the University of Cambridge has noted that "this is a major focus of research that we have to address, as the economic burden of brain disorders in the UK is expected soon to exceed £100 billion. With this microscope we have a world-leading tool to help understand drug delivery coatings, implant degradation and ion transport to bring us closer to delivering useful and scaleable therapeutics."

Potential applications are very varied. Dr David Kent from the Department of Haematology will be using NanoFab for clinical use in bone marrow transplants to understand how to expand adult hematopoietic stem cells outside the body. Professor Ottoline Leyser and Dr Raymond Wightman from the Sainsbury Laboratory will be advancing work on key plant sciences research.

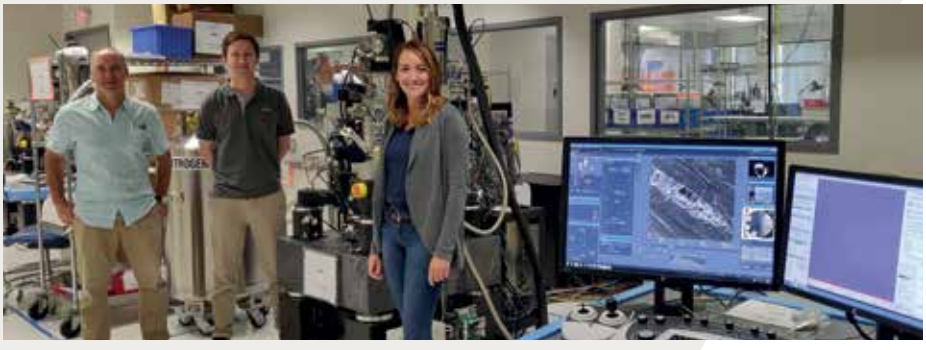
Applications for nanoscale fabrication studies span several research groups across Cambridge departments, including work by Professor Paul Midgley in Materials Science, examining how to fabricate devices at nanoscale. Other early users anticipating valuable advances in research capability include groups from the Wellcome Genome Campus and the Centre for Process Innovation.

Why has the IfM been actively driving the bid?

Our involvement from the beginning of this project has centred around our work in nanomanufacturing and scale-up. There are many challenges when scaling up the latest emerging technologies from the lab to full-scale manufacturing. In particular, emerging product or material technologies face the challenge of maintaining their novel functionality when produced in increasingly real-world manufacturing environments, at realistic process throughputs, and using standard manufacturing tools.

If we work with the latest biomaterials to grow replacement tissues and organs, with nanomaterials that can deliver drug therapies or personalised diagnostics, or with any of a raft of exciting new technologies, then we are not only relying on chemical and interfacial properties at the nanoscale, but we are purposefully designing them to carry out the required task.

Every step required to process, shape and package these materials is a risk to the carefully chosen structures and chemistry. This means that when carrying out manufacturing research we have to be able to study materials at the nano and sub-nano scale using techniques that won't compromise their structure. We also need to be able to accurately cut into samples to see what lies beneath the surface. This is especially difficult for soft matter and biological matter characterisation and analysis, because traditionally this matter needs to be completely dehydrated and coated in a thin metal layer to stop charge from building up and to enable imaging at the nanoscale. Orion NanoFab changes this.



IfM's Ronan Daly with David Ferranti and Rebecca Elston of ZEISS during the initial testing of the Cambridge Orion NanoFab at the ZEISS lab in Peabody, Massachusetts.

Leading one of the IfM's research projects, Professor Bill O'Neill will be using the incredible machining precision of the Orion NanoFab, and specifically looking at how to link this technology with higher throughput machining processes. Helium and neon milling is still too slow to rely entirely on this technique in an industrial context. Bill has, over the past five years in the EPSRC Centre for Innovative Manufacturing in Ultra Precision, been developing hybrid laser-ion production systems to increase productivity whilst maintaining the resolution limits of ion sources. Incorporating this latest tool into the hybrid laser–ion process chain will lead to significant advances in nanofabrication techniques and technologies.

Reaching out

Acquisition of Orion NanoFab received active support from Pro-Vice Chancellors for Enterprise and Business Relations (Professor Andy Neely) and Research (Professor Chris Abell). They will be key to linking this investment to broader strategic and policy initiatives. Both were invited to join the team because of the significance to both the research and industrial communities.

The strategic importance of a shared world-class asset which facilitates greater collaboration and advancement of scientific research fits closely with the mission of the University of Cambridge to contribute to society through the pursuit of education, learning, and research at the highest international levels of excellence.

Once in place there will be studentships supported by ZEISS to help PhD students explore the full capability of this exciting tool.

To raise awareness widely, there will be efforts to engage with academic and industrial researchers to inform them about Orion NanoFab and how it could support their work. The team behind the bid is actively reaching out to all parties, presenting Orion NanoFab's capabilities and access procedures to deliver a new, much-needed UK resource.

Collaboration as the best medicine

Collaboration can be pivotal in making change happen. So how can new collaborative models be forged in areas where such relationships are not well established, but where change is required?

In UK medicines manufacturing, there is an opportunity and a pressing need for progressive change. But there are also plenty of challenges and obstacles, particularly in a highly competitive and tightly regulated sector. A bold step forward has been taken over the past four years through a collaborative £23m project, ReMediES, involving 22 industry partners and two leading UK Universities.

As ReMediES concludes its work and passes on the baton, we talk with the IfM's Dr Jag Srai, Research Director on the project, along with some of his colleagues in ReMediES, to reflect on how the project has forged a model for change through collaboration.

Medicines manufacturing is an important part of the UK economy, employing 40,000 people and generating $33 billion in exports. In many ways, it is productive, strong and successful. However, there is potential for making significant improvements across the medicines manufacturing supply chain.

The pharmaceutical industry's size, scale and complexity, alongside its highly-competitive character, have made change difficult. There is an entrenched pattern of long product development cycles with high attrition rates, leading to development costs of around $2.6 billion per product. Clinical trials often take place many months after the trial drugs have been manufactured, resulting in significant stock write-offs of 50% or more. The commercial supply chain has become cumbersome and inventory-heavy. Furthermore, the sector is highly regulated, which instils caution.

While this status quo may sound problematic and somewhat bleak, in fact it has provided a much-needed stimulus for industry players to seek improvements, and a motivation to reach over those high competitive walls and collaborate for mutual benefit.

Remedies for change

Dr Jag Srai, Head of the Centre for International Manufacturing at the IfM, has been working with major players in the pharmaceutical industry for several years.

He comments:

"Medicines manufacturing needs to embrace new production and digital technologies that can support more responsive inventory-light supply chains, able to deliver medicines that are more targeted to specific patient groups or even personalised to individuals, with the potential to revolutionise healthcare delivery. This is too much for a single company, even a multinational, to achieve in isolation.

"So as a step in the right direction, we developed a vision for a large pre-competitive collaborative project to drive change, with the active participation of the regulator."

In 2014, the ReMediES (Reconfiguring Medicines End-to-End Supply) project was launched, bringing together 22 industrial partners including global pharmaceutical companies GlaxoSmithKline and AstraZeneca, as well as major contract manufacturing organisations, equipment manufacturers, international logistics specialists and a global pharmacy. The University of Cambridge and University of Strathclyde provided expertise in supply chain and pharmaceutical product and process engineering.

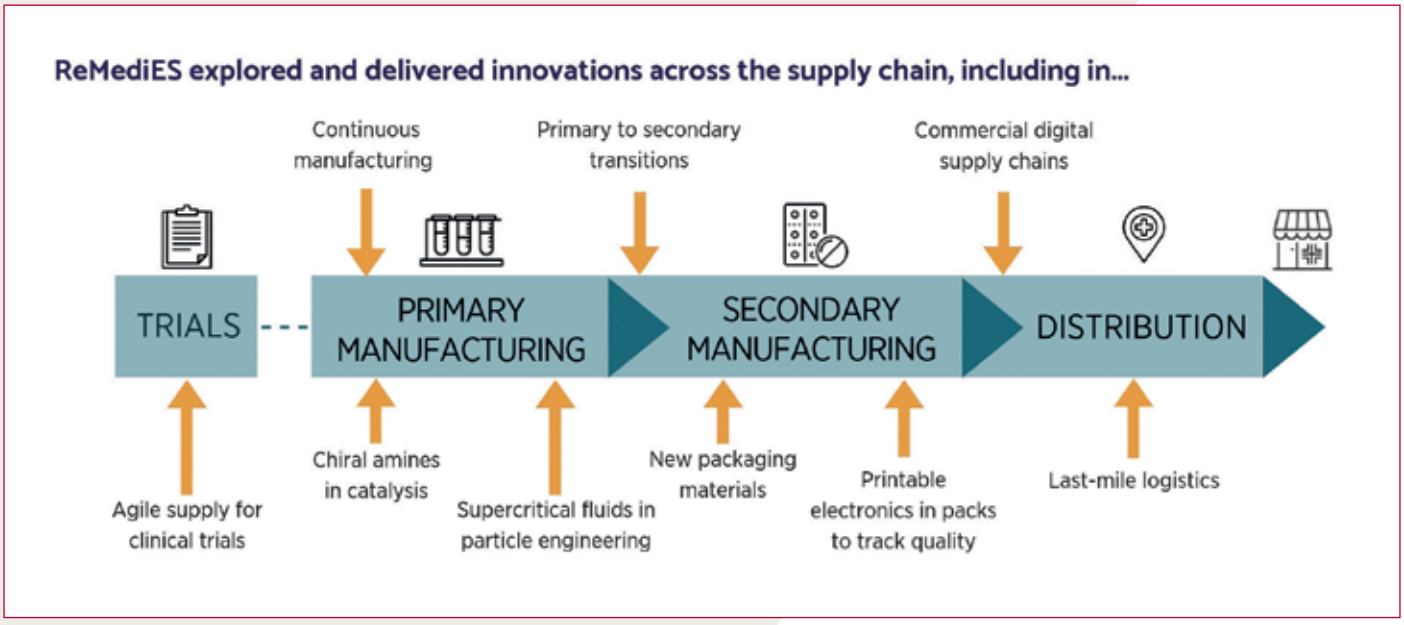
This broad partnership addressed some of the key challenges facing small molecule medicines manufacturing, with eight workstreams focusing on different aspects of clinical and commercial supply chains. Jag, as Research Director of the project, explains:

"Across the ReMediES workstreams, we have attempted to tackle some ambitious questions. Can we run our clinical trial production more efficiently 'on-demand', reducing waste, inventory and lead-times? Can we adopt advanced technologies to make both our primary and secondary manufacturing processes right first time, more environmentally sustainable and capable of responding to changing demand? Can we apply science to create more soluble medicines? Can we package medicines in ways that will reduce wastage and help with patient compliance? And can we get better at delivering drugs to the people who need them, when they need them?"

Over its four-year timescale, the ReMediES partners worked to tackle these essential, cross-sector, cross-functional challenges. The partners were able to take fundamental and applied research through to prototype or commercialisation.
Dr Clive Badman, former Vice President of Pre-Competitive Collaboration at GlaxoSmithKline, was instrumental in forming the ReMediES consortium and became its Project Director.

He comments:

"Many of the firms have experimented with some of the technologies we are talking about in ReMediES, but have not had the scale and the expertise that the ReMediES consortium offers to take things forward."



So what were the positive outputs from this collaborative approach? As the project reaches the end of its funding, partners have been reflecting and reporting on some of its key achievements.

The Supply Chain Reconfiguration Lab at the IfM

Clinical supply chains – 'just-in-time'

Clinical trials are a critical part of pharmaceutical R&D, but are increasingly complex to manage, often involving thousands of patients at hundreds of sites in different countries. At the same time, the sector wants to bring new medicines to market more quickly and more cheaply.

In the current system, it typically costs in excess of £75 million to run a clinical trial for a new drug; an enormous cost considering only 25% of drugs trialled make it into commercial production.

Because the sector is still reliant on high-volume production techniques it has to manufacture a trial drug in large quantities, often before the patients have been recruited, sometimes without confirmation that the trial is going ahead. Clinical teams have to decide doses and quantities of a trial drug to be manufactured 12 to 18 months before they expect to use it. As a result, more drugs are made than are needed to cover contingencies.

The process is also not sufficiently agile to respond to the changing circumstances inherent in any trial. For example, early results might suggest altering dosing or randomization strategies.

The ReMediES clinical trials workstream looked at how this could be improved, with the ambitious aim to cut supply time from 4-6 months to less than a week, and develop the ability to be agile to changing trial needs.

Project Lead, Andrew Dwyer from GSK, explains:

"We prototyped a new 'just-in-time' clinical pharmacy that can provide drugs to support complex drug trials, thereby reducing costs, increasing responsiveness and enabling a more flexible and exploratory approach to clinical research.

"The modelling of stock implications for a made-to-order facility has demonstrated that the potential benefit of an automated clinical pharmacy could be savings of tens of millions of pounds per year per company."

Primary manufacturing – from batch to 'continuous processing'

The challenges at the primary manufacturing stage are similar to those facing the clinical supply chain: a reliance on the overproduction of stock to mitigate a lack of agility in the supply chain, creating a high level of wastage. The sheer scale of batch manufacturing means that mistakes are expensive. If something goes wrong in a 10,000 litre vessel, the waste of energy and materials is significant. In continuous manufacturing, on the other hand, the process is constantly monitored and adjusted to ensure quality.

Through a number of related projects, ReMediES has made significant progress in developing new chemistries and processes that support the move from batch to continuous manufacturing, shrinking factory scale, increasing speed and reducing cost.

It has resulted in:

- New equipment for continuous processing with immediate commercial applications that support right-first-time manufacturing, yield improvements and inventory reduction.
- The development of a new GMP supercritical fluid manufacturing facility in the UK.
- Significant advances in biocatalysis and the use of enzymes in flow.

Secondary manufacturing

A major three-part project in secondary manufacturing has piloted new equipment for capabilities that enable shorter production cycles and volume flexibility.

Liz Meehan, responsible for Pharmaceutical Technology and Development at AstraZeneca, and workstream project leader for ReMediES, comments:

"A more flexible and agile medicines supply chain will be enabled by wider implementation of advanced (continuous or additive) manufacturing processes for both drug substance and drug product."

The ReMediES project included user trials and case studies for some strategic technology platforms including continuous drug substance isolation, continuous direct compression, hot melt extrusion and 3D printing. As Liz explains:

> "By taking a multidisciplinary approach, ReMediES has shown how these advanced manufacturing processes can be deployed and accelerated to meet the challenges of future clinical and commercial supply chains."

The result will be substantial reductions in the cost of production, estimated in one company alone at £10m per year once fully implemented.

Smarter packaging

The ReMediES packaging workstream, in which AstraZeneca and GSK have collaborated closely, looked at using new materials and processing techniques to improve blister pack moisture barrier properties whilst at the same time reducing their size, leading to significant cost-savings and reductions in environmental impact.

This production process, now going to full trial, suggests a 10-fold improvement in moisture barrier compared with other similar cost materials. For one company alone it could mean, based on an example application for a leading product:

- A reduction in CO_2 emissions of 700 tonnes annually.
- Savings of around £380k for materials and £1.5 million on distribution.
- A material productivity increase of 25%.

The ReMediES team, led by the Centre for Process Innovation (CPI) also developed smart labels for use on medicines packaging using printed electronics which enable product tracking, monitoring and could be used to support patient engagement. Successful demonstration is leading to commercialisation opportunities that are being pursued with leading packaging manufacturers.

For further information:
www.remediesproject.com
Or contact : Dr Jagjit Singh Srai
jss46@cam.ac.uk

Digitalisation of commercial supply chains

Several projects have underpinned the development of future supply chain models led by the team at the IfM.

Drawing data from 138 companies and 34 research organisations an asset library for use across the industry was developed in the form of a 'capability matrix' setting out what asset capabilities exist across the extended supply chain. This was then expanded using data-mining of commercial databases, to identify collaborative relationships in key capability areas. An interactive digital platform tool was created for use by ReMediES partners to interrogate the current collaborative network across the UK pharmaceutical landscape for specific asset capabilities, and to foster future collaboration.

A number of projects were conducted on the use of specific digital technologies across the end-to-end supply chain. These include an electronic patient-information leaflet, developed in consultation with the regulator. This is designed to co-exist or replace the paper version used in medicine packs with a prototype mobile phone app providing patients electronic access. The hope is that such innovations can increase patient compliance and reduce waste.

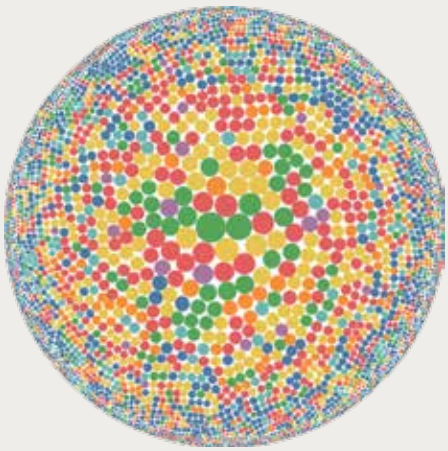
An end-to-end supply network design, analysis and modelling platform has also been developed to help manufacturers understand the opportunities available to reduce inventory and increase speed-to-market. The multi-layer modelling platform allows organisations to evaluate new production processes, how these might influence production location and scale, inventory requirements of segmented product portfolios and market service levels.

The Supply Chain Reconfiguration Lab at the IfM

As Jag commented on the work in his Centre being led by Dr Ettore Settanni:

"We can slice and dice a range of data to observe the interplay between cost, service and environmental resource efficiency in an integrated way: from a unit operations production processes perspective, a manufacturing footprint analysis and the final distribution of medicines to patients - rather than the functional 'silos' in which new technologies are often assessed"

The workstream also analysed 'last-mile' logistics, with global pharmacy Alliance Healthcare, and the life sciences division of the logistics specialist, DHL, as part of the ReMediES project. Adopting approaches used by the IfM researchers in FMCG and retail distribution logistics, the team modelled direct supply to patients to evaluate feasibility in terms of cost and service levels.



Visualisation of numbers of prescriptions being processed by pharmacists in selected postcodes over the course of a month

It has not all been hard work and no play – the team have, for example, used gamification to develop a mobile app helping industry experts and multiple supply chain stakeholders within the ReMediES programme to evaluate otherwise complex risk interdependencies across the extended supply chain. This work links well with a broader disruption risk assessment tool available from ReMediES partner Intersys, now marketed commercially.

What next?

The work of ReMediES will continue through the new £56 million Medicines Manufacturing Innovation Centre (MMIC), located in Glasgow, which is jointly funded by Innovate UK, Scottish Enterprise, GSK and AstraZeneca. MMIC is designed to help both start-ups and multinational pharmaceutical companies adopt novel processes and technologies and customise them to integrate with their own manufacturing processes. Just-in-time clinical pharmacy and continuous direct compression are MMIC's first 'Grand Challenges', taking forward the work of two of ReMediES's core projects.

Forging a model for collaboration

Whilst new technologies are offering major opportunities to patients, healthcare providers and manufacturers, they require new collaborative platforms to address the complex technical and regulatory challenges that are involved. It's too big to do alone.

However, the concept of pre-competitive collaboration is relatively new in the medicines manufacturing arena, and many companies are concerned about becoming engaged from a cost and IP perspective. ReMediES addresses this concern in part by providing an exemplar collaboration model where innovations emerging from fundamental and applied research can be taken to prototype or commercialisation. The collaboration has enabled multi-stakeholder perspectives to be considered, drawing in expertise from technology providers, regulators, academia and industry. Individual firms have been able to leverage their resources, upwards of 50% on direct activity, and by over 300% at a programme level.

Dr Will Barton, Chairman of the Advisory Board of the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing, was the independent advisor to the ReMediES Project. He comments:

"ReMediES was one of the early examples of the pharmaceutical industry working together in collaborative R&D, something it didn't have a record of doing before. The project has shown the value of such collaboration, that you don't have to share your crown jewels and that there are a lot of areas where companies can work together if they choose to, which can benefit the whole industry."

"ReMediES was a well-run project that will deliver some early wins for the SMEs and longer-term impacts across the board. It was really exciting seeing teams deliver great results. Things happened that nobody would have believed possible at the start."

Developing technology experts as leaders

IfM's Executive & Professional Development (EPD) team, in partnership with Atos and Paderborn University, has been recognised through the prestigious EFMD Excellence in Practice Silver Award for its professional development programme.

The challenge

Atos is a global leader in digital transformation with around 100,000 employees in 72 countries. The Group is the Worldwide Information Technology Partner for the Olympic & Paralympic Games. In its solutions and services business, Atos wanted to develop its business technology experts to be trusted advisors for customers, equipped with the strategic perspective and business acumen to complement their technology knowledge.

The Gold for Experts programme was designed to address leadership development for people with a broad technical background, and make sure that it remained relevant and up to date in the ever evolving world of Atos and information technology. It would also need to take the changing internal business structure and environment into account as well as align with the growing ambitions of the organisation.

The partnership

To achieve this, Atos forged a partnership with the IfM to co-design and deliver a bespoke executive and professional education programme. Paderborn University adds Computer Science expertise to the partnership, leveraging an existing 30-year strong research collaboration with Atos, initially developed by Siemens.

The programme is a combination of three one-week residential modules, a major project, and webinars. The modules include interactive taught sessions, facilitated workshops where proven tools are learnt and applied, simulation exercises, and project discussions and presentations. A collaborative and cooperative learning environment is maintained throughout the programme to maximise delegate learning from the programme and from each other.

Tim Minshall facilitating an exercise on disruptive innovation.

The EFMD Excellence in Practice Awards recognise outstanding examples of effective and impactful leadership and development interventions between partner organisations. It is credit indeed to the IfM's EPD team to receive a Silver Award in the Professional Development category for its partnership with Atos and Paderborn University. This globally recognised award is a first EFMD Award for the University of Cambridge and for any university Engineering department.

'Gold for Experts' was first run in 2013/2014 and is a six-month programme with a combination of taught modules and a major project. This programme, now running for the tenth time, has met the challenge laid down by Atos and is now the cornerstone of Atos' Expert career track to develop the leadership skills of people with a technology background.

By the end of the programme, delegates are enabled to combine broader, end-to-end technical knowledge with understanding of the global business context and how it is changing. The objective is to transition delegates:

- From a 'focused' expert to an expert with a strategic 'end-to-end' view who can connect their role to the bigger Atos picture and appreciate the impact of their work on different stakeholders.
- From a 'local contributor' to a 'networked influencer' who can proactively shape innovative Atos solutions and strategy.
- From a 'technology expert' to a 'technology entrepreneur' who can co-create innovative solutions to meet client business needs.
- From a 'problem solver' to a 'trusted advisor' who is sought after by clients, colleagues and partners to help them anticipate and navigate future challenges.

The strength of this unique partnership has exceeded expectations:

"Gold for Experts has been in place for 5 years now and has trained 300 talents. The programme was designed together with two leading European universities to deliver the best possible experience. This unique combination has proven to be an efficient and successful way to further develop our experienced expert leaders." Hubert Tardieu, Advisor to Atos CEO and Founding member of the Atos Scientific Community.

"I have benefitted so much from the learning experience in Gold for Experts, not only from the excellent courses but also the sharing and exchanging of knowledge amongst experts from various service-lines, backgrounds and geographical locations. To me, the programme did not end on the day when the course completed, it's a continuous learning and transformation journey which shapes my thinking and confidence in becoming the trusted advisor to our clients." SOO SHIN PUAH, ATOS DELEGATE, MALAYSIA

Real projects to achieve learning and business outcomes

Undertaking real projects to create impactful learning is a core part of IfM's teaching practice. Group projects run throughout the entire programme culminating in a presentation made to Atos senior executives on the final day. The projects require delegates to work in teams of five people and tackle a real and significant opportunity for Atos, and propose a solution that generates value for clients and Atos alike.

This opportunity to develop innovative technology ideas is recognised as a source of innovation in Atos. 60 projects have been completed to date, and continue to attract significant interest from Atos senior executives. Of these projects, 65% have been taken further for organisational impact or to add new or enhance existing portfolio items and the remaining 35% have contributed to valuable strategic decision making.

The ongoing impact

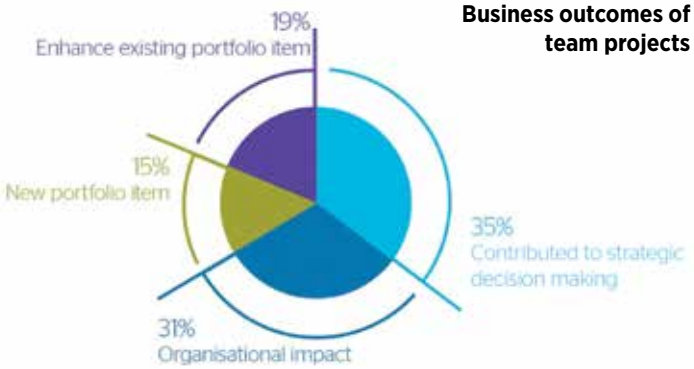
To date, the programme has welcomed 300 delegates from 23 different nationalities across all entities of Atos. It continues to deliver impact for Atos, with 96% of alumni retained in the company.

The programme's impact also includes increased cross-division integration of senior experts, as well as an active global network of alumni sharing ideas and best practices.

80% of delegates are shown to be actively pursuing personal and professional development after completing the programme. There is a clearer career path for the expert community, and promotion of participants is twice as high as comparable profiles.

For ongoing improvement of the programme itself, substantive feedback is collected from delegates and Atos stakeholders and a stringent review process is held to refine and improve the programme and keep it aligned with current research and Atos strategy.

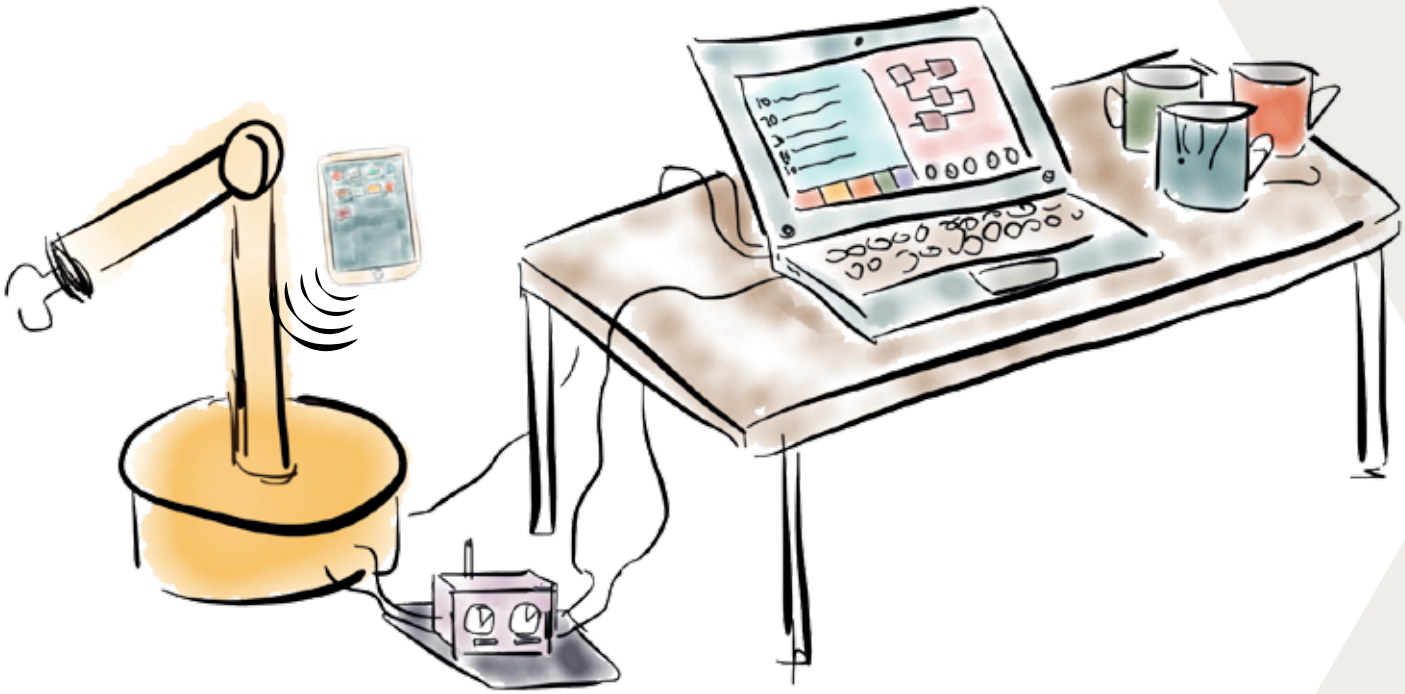
Business outcomes of team projects



For more information about our bespoke Executive & Professional Education, please contact Dr Judith Shawcross, jks45@cam.ac.uk

Digital manufacturing on a shoestring

Professor Duncan McFarlane introduces a new research project into low-cost digital solutions for manufacturing SMEs.



'Digital Manufacturing on a Shoestring' is a project with a difference. It asks how existing and readily available digital technologies could be implemented on a low-cost basis to support growth and productivity in small and medium-sized enterprises (SMEs). Rather than implementing digital at all costs, we address the common concern that recent developments in digital manufacturing are unlikely to be affordable for SMEs.

Our emphasis is on understanding the business challenges that organisations are trying to overcome, then creating appropriate digital solutions that demonstrate significant value and will deliver extensive impact across the SME community.

The problem for SMEs

Manufacturing organisations are increasingly seeing information as a key strategic addition to their product offerings and as a productivity gain for their processesses. Major innovations in computer science, control and informatics have created new opportunities for breakthroughs.

But most knowledge in this area has been focused on expensive solutions. This leaves a critical challenge around how to support SMEs with digital manufacturing transformation, particularly given the high costs not only of investing in advanced technology but also of upgrading industrial computing and communication environments to support it.

We are seeking to exploit low-cost commercially available technologies for mobile computing, sensing and artificial intelligence (AI), and to tackle the challenges associated with integrating these safely and securely into a small scale manufacturing environment.
We are working with partners such as Raspberry Pi to explore off-the-shelf non-industrial digital technologies that can be implemented 'on a shoestring'.

What will the research involve?

This unique project will see organisations working with the University of Cambridge and the University of Nottingham helping SMEs to develop digital solutions for their unique requirements.

As well as conventional research activities, the project will involve student hackathons as a means of stimulating low cost digital developments. There will be competitions to encourage undergraduate and graduate students in engineering and computer science to contribute software and hardware development. We also intend to run workshops targeted at local start-up and SME IT communities to engage them in the development of applications and products.

Through this co-development, we will advance the research and application of a number of cross cutting technologies, supporting the uptake of digital manufacturing within the SME community.

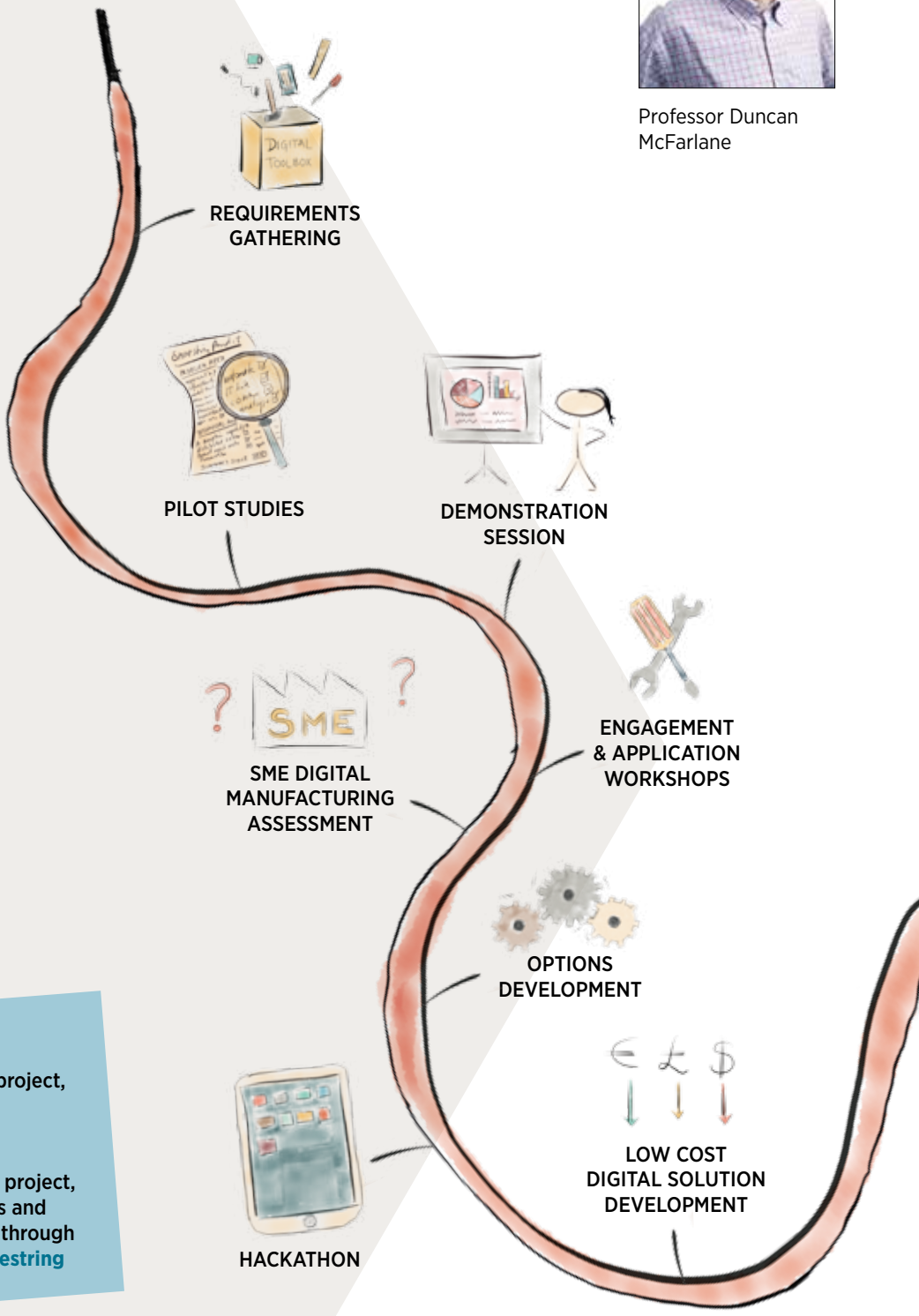
We hope to introduce into SMEs new methods of production that take into account the latest control, communication and AI technologies in a sector characterised by limited capital investment and research potential. Stretch targets for the programme include the introduction of low-cost product tracking, exploiting emerging industrial Internet of Things platforms and AI-based flexible control using commercially available AI and voice recognition development environments.

Get involved

If you would like to be involved in this project, register your interest by emailing dial-admin@eng.cam.ac.uk

Stay up-to-date on the progress of this project, including dates and times of workshops and demonstrations by signing up to alerts through the website: ifm.eng.cam.ac.uk/dmshoestring

Shoestring activities



Professor Duncan McFarlane

UNIVERSITY OF CAMBRIDGE
Department of Engineering

IfM MANAGEMENT TECHNOLOGY POLICY

EPSRC
Engineering and Physical Sciences Research Council

University of Nottingham
UK | CHINA | MALAYSIA

Describing skills: the art of the specific

Describing a skill using only one or two words is something we do frequently. But it can create difficulty, because it can imply different things to different people, depending on their experience and context.

When it comes to developing students for transitioning from education to work, this is particularly important. In order to acquire and develop a skill needed for the workplace, it is important to unpick what it involves more closely. Judith Shawcross, Head of Executive & Professional Development at IfM ECS and Programme Coordinator of the Manufacturing Industry Education Research Group, explains some insights from her research into this.

Can you make a cup of tea? How do you visualise the process? Are you in a familiar kitchen with a kettle? You're imagining performing a skill, and most likely it's one you feel you can do fairly easily.

But think about it in a different context. Imagine you are in a forest or up a mountain, and to make tea you first need to light a fire. Maybe you don't even have matches. In this context, the skill of making tea becomes more complicated and difficult than using a kettle in a functional kitchen, and brewing a drink appropriately. It now encompasses other skills which are challenging in themselves, such as gathering useable firewood, building a fire, lighting the fire, hanging a pot over the fire...

Lost in translation

Similarly, the ability to perform a professional skill in one context is not always directly transferable to another context. Skill descriptions like 'computer programming', 'data gathering', or 'report writing' could differ widely in their precise definition and scope between professions, industries, even between teams or team roles, and in interpretation depending on individual experience.

High-level descriptions of skills are usually inadequate for communicating exactly what is expected. For example 'project management' does not convey what exactly someone might be expected to do, especially when the type or size of the project and its context are not detailed.

The limitations of the English language (in which words can have multiple meanings) adds further complication, combined with the practice of different communities adopting words for specific situations. The skill of 'lacing' could, for instance, refer to lacing shoes, lacing cables, making lace fabric trimming or lacing beads.

Nuanced meanings in words can also shift in translation between languages, another issue which makes describing skills even more problematic given the increasingly international work sphere.

Skills for effectiveness at work

These subtleties around describing skills present a challenge for transitioning from education into work.

We considered this education-to-work transition through the example of preparing students for work experience placements. Students on the IfM's one-year ISMM graduate programme undertake four Short Industrial Placements (SIPs) as part of their course, each time spending two weeks within a company working on a real and significant issue for that company.

The expected outcome from a SIP is a clear, evidence-based definition and analysis of a problem, and a business case to support the implementation of a solution. From the company perspective, these placements provide real analysis and are often highly praised by the host firm as delivering genuinely useful feedback.

For the students, 'learning by doing' is recognised as a key strategy for developing graduates for work readiness, giving them

insights into how to adapt and apply different knowledge in diverse contexts.

In terms of skill development, work placements help students develop a broad range of skills, from practical implementation skills for the process-driven aspects of completing the project, through to interpersonal and self-management skills.

To get the most from the placements, students need to acquire some basic skills and understand how they may need to deploy them. We prepare them for their first SIP through an introductory lecture and a series of five different practical industrial problem solving simulations, such as reconfiguring a factory layout to improve operational efficiency.

Break it into tasks

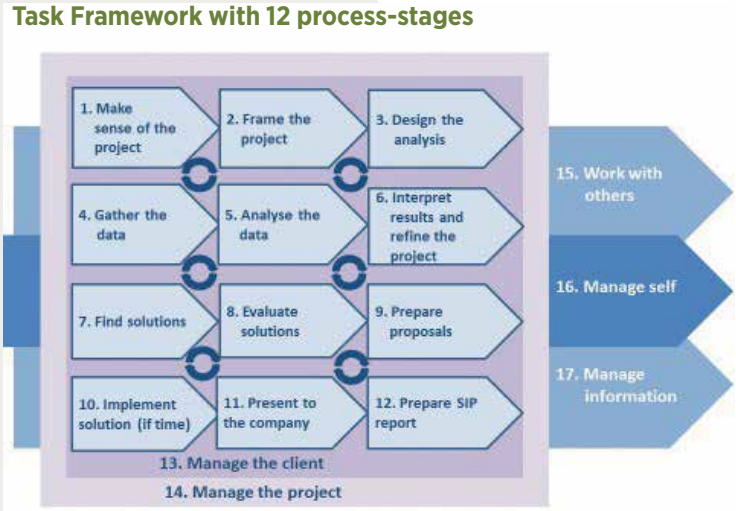
A key part of teaching and learning the required skills relies on being able to describe them. Describing tasks involved in performing a skill is a good place to start because a task, and the context in which it is performed, determines the skills required – as shown in our earlier example of making tea.

We constructed a 'Task Framework' from literature, which provides a way of organising and communicating tasks in a structured way, giving a holistic view of the tasks required to undertake a type of work. This was then tested in multiple ways with the students over their four different SIPs resulting in a Task Framework with 12 process-stages, and five 'generic' domains, as shown in the diagram. The circular arrows reflect the interconnectedness of the 12 process stages.

Each of the process-stages (numbered 1-12) includes a number of tasks, which could then be listed. For example, stage 1 'Make sense of the project' can be sub-divided as shown in the table.

Whilst this does not describe skills, it enables skill development by listing the tasks which can then be practiced in relevant contexts.

Task Framework with 12 process-stages



Example of detailed process-stage

Process Stage	Description	Task
1. Make sense of the project	Assimilate company and project context. Develop a clear understanding of the project brief. Identify key stakeholders and their expectations.	**1.1** Discuss project brief with ISMM Tutor and SIP partner
		1.2 Identify key technical knowledge and/or tools/techniques likely to be required and ensure relevant resources are accessible
		1.3 Assimilate publically available company information
		1.4 Assimilate market/industry information
		1.5 Assimilate information about company challenges/issues
		1.6 Dissect a project brief to determine areas to question
		1.7 Discuss project brief with company and determine key stakeholders and their expectations

Are 'people skills' even harder to describe?

We also identified 'generic task domains' which span a project. These are i) manage the client, ii) manage the project, iii) manage information, iv) work with others, and v) manage self.

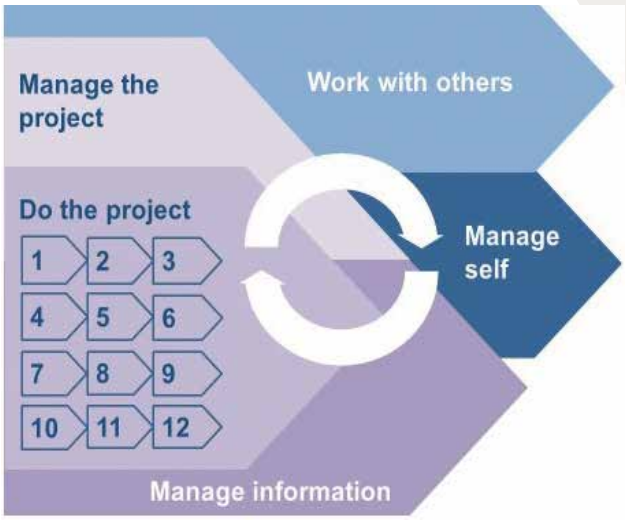
The first three of these (managing the client, the project and information) are tied to project delivery, and closely related to the process stages. They can be described using a similar task-based framework to that shown in the table.

The final two (work with others and manage self) are people-centric domains essential for successful work placements. Describing these is more elusive, but very important, because these are often the areas which present the biggest transition for students moving from education into work.

As with many problems, we tried to tackle this by breaking it down. We collected data from the students to understand it from their perspective. Could 'manage self' be made up of a range of subcategories which were easier to describe? We identified five: health, thinking, 'being

myself', 'being professional' and 'managing my work'. Interestingly, around 20% of the student data collected described behaviours and not tasks: for manage self, 16 associated behaviours were identified, with 'being focused' and 'being open-minded' described the most often.

The research found that the generic domains were much more extensive than previously captured, and we needed to modify the Task Framework to reflect this, as shown. In this version, the three purple domains are closely interlinked and are delivery-centric, whilst the two blue coloured domains are people-centric and underpin delivery. The large circular arrow depicts the domain interconnectedness.



Transition to work

Why is this so important? Why in particular does it help to describe the 'generic' interpersonal and self-management skills?

Students find themselves needing to make a significant adjustment to their sense-of-self as well as understanding the expectations that others may have of them when they move into a professional sphere of work. Through their years in education, they will usually have been in a controlled environment, been accustomed to working mostly with people their own age, and had a set of clear expectations focused on a single outcome (passing an exam or course). Young people have developed their sense of identity within this context. Switching to a professional environment, with less clarity around expectations, a wide range of people in terms of age and experience and less clearly measured 'success criteria', requires a shift in a graduate's self-perception.

In addition, academic courses such as Engineering tend to cover neatly defined, bounded problems with clear objectives and sufficient data. Workplaces rarely work in the same way. Problems are typically ill-structured and complex, and often have vaguely defined, unclear goals. These will usually have non-engineering success standards and constraints. So graduates need to make a significant adjustment, requiring personal flexibility and adaptability.

Industrial work placements are used in a variety of ways in different educational settings and help to give students a deeper insight into this significant change in expectations. As such, work placements are widely recognised as an effective method for helping students bridge this gap.

Finding better ways to describe the skills needed for work placements should help University staff and students to prepare for placements and ensure that they are good learning experiences, as well as better equipping them for the transition from University to work.

In particular, adequately describing the generic aspects of the work Engineering graduates do in industry has the potential to significantly improve Engineering Education because it will enable these aspects to be communicated, taught and assessed.

Dr Judith Shawcross

Unlocking ideas through open innovation

The Open Innovation Forum is a consortium of food and drink companies taking a collaborative approach to innovation. Dominic Oughton, Principal Industrial Fellow with IfM Education & Consultancy Services, explains why this is a compelling strategy for businesses in the FMCG sector and beyond...

The companies most likely to thrive in the complexity, speed and uncertainty of today's global business environment are those able to innovate effectively. This increasingly calls for firms to be ready to collaborate beyond their own walls.

Companies cannot afford to rely entirely on their own research, or assume that all the best ideas can be generated internally. As Bill Joy of Sun Microsystems famously commented "No matter who you are, most of the smartest people work for someone else." The wisest business leaders are those seeking to work with others, and looking for partnerships in innovation.

In sectors like food and drink and FMCG, forward-thinking companies have been identifying opportunities to create value, by challenging a rigid insistence on traditional 'closed' approaches to R&D. A closed approach would emphasise confidentiality over openness, and internal capabilities over external strategic partnerships. Open Innovation refers to a broad approach that offers a bright alternative.

Open Innovation Forum: A collaborative model

Building on OI research by the IfM's Professor Tim Minshall and Dr Letizia Mortara, the Open Innovation Forum has developed over the past nine years with companies in the food and drink and FMCG sector coming together to share OI best practice, explore hot topics, and engage actively with research. Members include industry-leading multinationals such as P&G, Walgreens Boots Alliance, Mars, Moy Park, Crown, Siemens, Domino, Heineken and PepsiCo among others. They span different echelons of the supply chain—manufacturers, raw materials and packing producers, machinery and ingredients suppliers, and retailers—enabling development of insights along the entire value chain.

The Forum considers OI to refer to a set of behaviours and processes that were in fact well established long before the phrase was coined in 2003. The OI 'brand' provides a convenient umbrella to discuss all aspects of collaborative innovation and partnerships between organisations.

The Forum's Roadmap, a powerful sector-specific tool used and updated by the members to identify key issues and trends, provides topics for focus at meetings. Workshops are held three times a year, hosted by a different member each time. Recent themes have included supply chain security, flexible batch manufacturing, intellectual property strategy, and plastic packaging. While broad underlying industry needs tend to remain the same – sustainability, health, productivity, quality – the strategies for achieving them and hot topics within them shift over time.

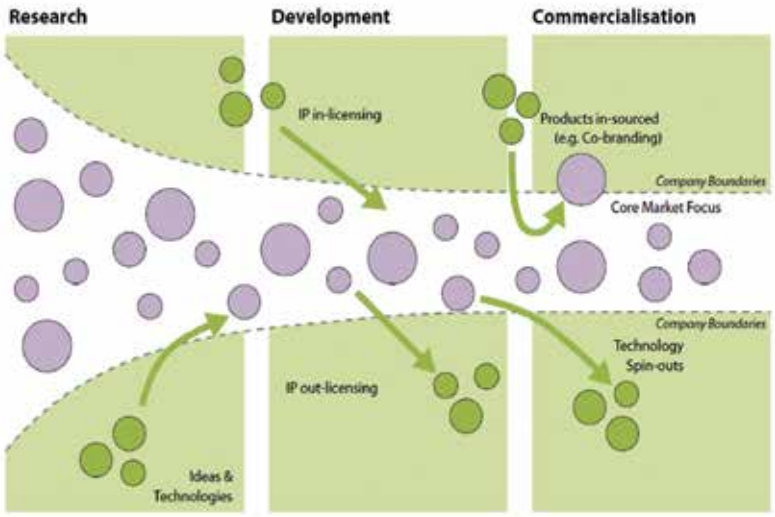
Sharing self-analysis

A key element of the Forum's work is the critical self-evaluation members undertake of their company's current OI approach,

What is open innovation?

Open Innovation (OI) involves embracing both internal and external 'ideas' and 'paths' to market. It moves away from the traditional organisational view that successful innovation requires strict control, towards a set of more 'open' principles.

The term 'Open Innovation' was coined by Henry Chesbrough, then at Harvard Business School. It provides an alternative model to the conventional funnel for new product development, in which companies invest heavily in research, taking a subset of those projects through to development, and a further subset through to commercialisation and market launch – a process which is slow, expensive, and fraught with risk, and often leaves good ideas behind (perhaps mistakenly) if not deemed sufficiently lucrative. Instead Chesbrough advocated OI "to accelerate internal innovation, and expand the markets for external use of innovation." He identified 'inward-out' and 'outward-in' flows of knowledge. The figure below depicts the open innovation funnel. The boundaries of the firm, represented by the dashed lines of the funnel, are permeable and allow ideas and technologies (the mauve and green circles) to pass in and out of the firm.
This model encourages companies to be more receptive to working with external partners, actively seeking paths to integrate external ideas into the company, as well as pursuing opportunities for spin-outs, licensing and co-branding.



enabling them to analyse their own strengths and weaknesses. This is also valuable for seeing trends and comparisons across the group, opening up discussions on different ways to address challenges and drive improvements. The opportunity to learn from the collective experience of the group, combined with research input and frameworks from the IfM, has become a significant asset to members.

Often strategies vary between companies. There are times when a more traditional approach to innovation is more appropriate, and companies may choose to keep certain areas 'closed' – for example when dealing with deep know-how that is important to the business, such as a secret recipe. Dr Serena Flammini at the IfM is currently working on further research to identify tools to support businesses in making decisions about when 'open' or 'closed' innovation is more appropriate.

OI in practice

OI can take many forms in practice. An example may be increased collaboration and information-sharing across an end-to-end supply chain. For example, traceability is a major concern for FMCG retailers and consumer groups, but the costs can end up falling heavily on one party in the supply chain such as the packaging company. If supply chain partners can find a joined-up process to share information without contravening IP or consumer rights, they can all derive value from the ability to provide better data on traceability, thereby benefiting their customers whilst dispersing the burden of risks and costs.

Dominic Oughton,
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Another example is co-creation. Outward-looking companies find proactive ways to encourage innovators to come to them with new ideas. For example, Heineken has created a web portal called Innovators Brewhouse which communicates challenges and encourages external parties to submit solutions. This has produced successful inventions such as the Heineken Blade, a countertop draught beer dispenser, which enables the company to target huge new growth markets for draught in the casual dining sector which can currently only offer bottled beer.

Siemens has also recognized the value of working jointly with partners and customers to create new solutions, and has created a co-creation toolset to support the process.

Combined innovative power: Small and large companies

One of the Forum's key aims is to facilitate big corporations to work alongside start-ups and SMEs. Large corporations need access to new ideas and technologies to feed their innovation processes. Small firms are significant generators of innovation but are typically resource constrained. So bringing together these companies in mutually beneficial partnerships harnesses the speed, entrepreneurship and innovative capacity of small firms to feed the channels, brands and resources of the large company, creating new value for consumers they could not deliver alone.

The Forum holds an annual pitching contest, an opportunity for start-ups and SMEs to pitch innovations to the members. The combined power of the Forum, with a significant global market share among the members, provides a huge opportunity for smaller enterprises. The contest usually focuses on common challenges identified by the Forum, seeking relevant solutions. Forum members may jointly invest in a new enterprise, which is good news for everyone as it spreads the risk and widens the opportunity for the innovator.

The Heineken Blade was developed as a result of encouraging external parties to submit innovative ideas.

Making Connections:

How TfL is mapping relationships for better results

The Cambridge Ecosystem Mapping Framework, developed by the Cambridge Service Alliance at the IfM, enables identification of value relationships between members of an ecosystem, and analysis of how that value could be increased for mutual benefit. The framework was recently applied for the first time to a large public sector project, mapping part of the ecosystem of Transport for London and its stakeholders. We talked with Dr Florian Urmetzer to find out more.

On any Friday evening, London's Leicester Square tube station is a throng of activity. Office workers head home after a long week, crossing paths with shoppers, tourists, theatre-goers, and those heading to restaurants, bars and clubs to start to their weekend. In a short space of time, thousands of other people come and go, relying on the tube to help them reach their destinations.

Like all the underground stations across London's bustling West End, Leicester Square forms part of a transport network that is the arterial system for the life blood flowing around the local economy. West End businesses, restaurants, theatres, shops, hotels and museums rely on this transport corridor, as do the institutions of government and state extending down towards Westminster.

All these varied commuter destinations represent local organisations, which are part of the 'ecosystem' of the West End's transport network. They are stakeholders who would be affected by changes to the operation of the London Underground. So as Transport for London (TfL) plans its improvement projects in the West End, how might it better understand its ecosystem, and consider how the organisations within it are likely to be impacted?

And in doing so, could it identify ways to work more effectively with the organisations within the ecosystem, and find opportunities for mutual increases in value?

Business ecosystems and value creation

Significantly, there are exchanges of value within a business ecosystem, in terms of how organisations can benefit each other. Dr Florian Urmetzer of the Cambridge Service Alliance (CSA) explains:

"Different types of value can be created and captured within an ecosystem. We distinguish between direct value exchanges, which usually involve money changing hands, and indirect value exchanges which are non-financial."

Value exchanges change at different stages of a project. If managers can pinpoint project stages when particular relationships are critical, they can better assess how they could be strengthened for mutually beneficial results. In order to do this, the relationships need to be identified and mapped.

CSA researchers have developed the Cambridge Ecosystem Mapping Framework to facilitate this. As Florian explains:

> "What we try to do is explore the question of how managers perceive the complexity in their value relationships. We then ask how this complexity can be used, described, and harnessed to provide better service or outcomes."

Developed initially with private sector partners, would the framework be applicable to large public sector infrastructure projects? TfL's West End Corridor (WEC) project provided an excellent opportunity to test this out.

West End tube maps?

Through focus group discussions led by a CSA researcher, the WEC project team created a visual representation of the ecosystem, and mapped the direct value transfers within it.

The Cambridge Ecosystem Mapping Framework involves nine steps:

1	Define the end customer	2	Brainstorm ecosystem members	3	Cluster ecosystem members
4	Create connections	5	Identify key relationships	6	Understand value proposition
7	Examine value exchanges	8	Create ecosystem innovations	9	Evaluate ecosystem innovations

The first step, defining the end customer, helped the WEC team to specify the beneficiaries of transport improvement. In addition to the direct benefits of a better service for fare-paying customers, the team could identify customers in a broader sense to include those who would benefit economically or socially from transport improvements.

Next the ecosystem members were identified and clustered – with 64 members in 13 clusters representing internal TfL teams, local community and community actors, financing organisations, infrastructure deliverers and public institutions. Ecosystem members include local, regional and national political players such as the Greater London Authority, Secretary of State, MPs, local councillors and the Mayor of London. It also includes other statutory bodies such as the British Transport Police, London Fire Brigade and the Environment Agency.

In step 4, the team mapped out connections between members. This led them to highlight an important aspect of public sector projects: the approvals process. As Jennifer Henderson of TfL explains:

"In terms of stakeholder requirements, public sector projects bring with them extensive requirements for approval and accountability, often with multiple layers of influence and decision making. Ultimately they demand accountability to the voter and tax payer."

Thus they identified two key types of direct value exchange. Direct financial transactions flow to stakeholders who are providing a service. Additionally, there are stakeholders with a more strategic relationship – identified by the additional direct transaction of approval. Both types of transactions change at different stages of the project.

Dr Florian Urmetzer

Building value in key relationships: TfL and the Mayor of London

The transactions maps made it easier for the WEC team to identify the key relationships and transfers of value at each stage of the project. They could then investigate 'ecosystem innovations': strategies to develop those key relationships to increase the value for both parties.

As a starting point, the team chose to focus on the relationship between itself and the Mayor of London. TfL is responsible for delivering the Mayoral Transport Strategy. Given that the Mayor holds elected office for a four year term, the team found that connecting its own project planning to the mayoral electoral terms provided better strategic alignment and could increase value for both parties.

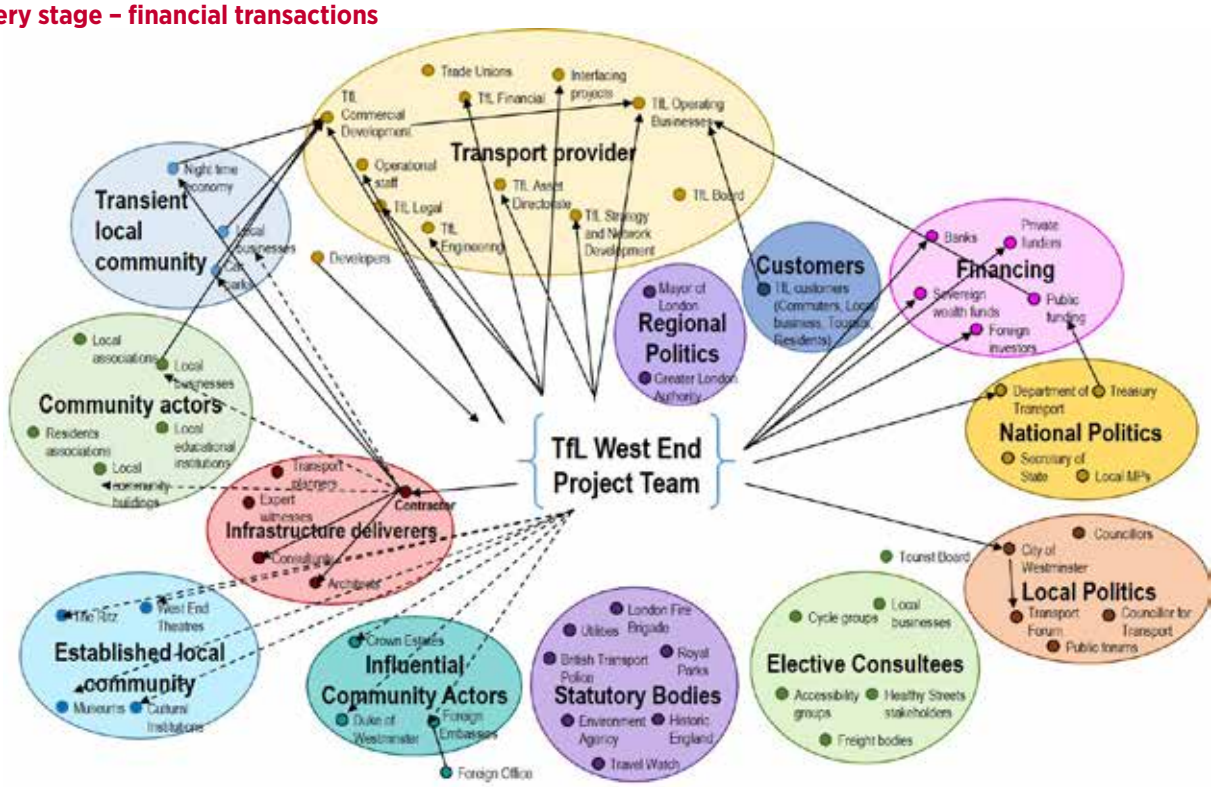
How would this work? The project team identified opportunities to phase delivery of project elements within the timeframe of mayoral terms. There are benefits to the Mayor through enhanced public perception, by demonstrating an ability to deliver on promises made to the electorate. There is also potential for better alignment of transport projects with other mayoral goals such as housing, air quality and public health initiatives.

In return, the value benefits to WEC would include increased likelihood of support and approval from the Mayoral Office. This would in turn lead to greater likelihood of funding and support from other parties.

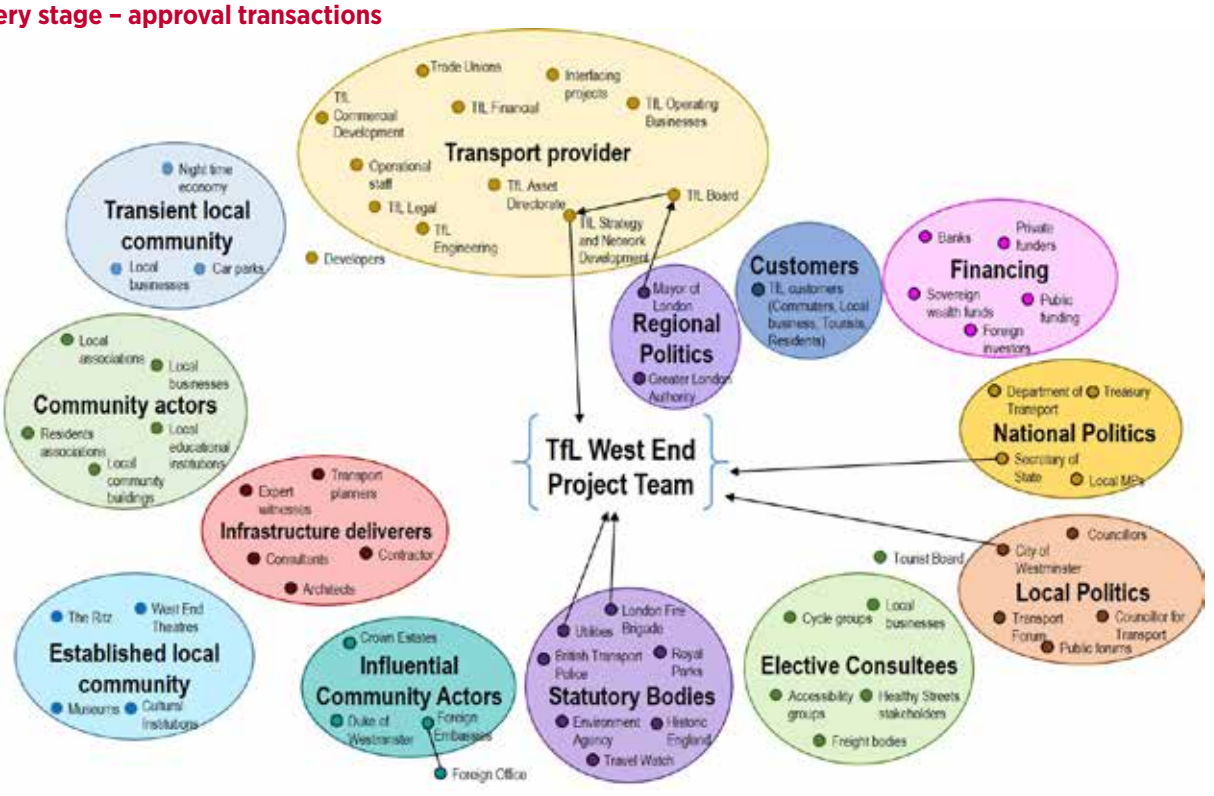
The team also identified that mayoral support early in the project is likely to lead to more efficient delivery and therefore reduced costs. Conversely, failure to build strategic alignment creates a disconnect between TfL and the Mayor, and is likely to lead to value slippage in cost and delivery.

In summary, mapping and understanding this pivotal relationship has uncovered innovations that can be created for better strategic alignment. Similar analysis of other key relationships is also likely to demonstrate opportunities for creating and capturing increased transfer of value in the ecosystem.

Delivery stage – financial transactions



Delivery stage – approval transactions



Intellectual property challenges for the digital economy

As manufacturers transition into data and digitally-driven business models, there are significant implications for intellectual property (IP). Dr Frank Tietze, Head of the Innovation & Intellectual Property Management research group at the IfM, considers five key challenges, and some strategies to address them.

In the story of the emerging digital economy, disruptors are bringing new ideas into the manufacturing industry with the potential to transform existing and discover novel ways of working.

The problem for the incumbent manufacturers in many industries is not only that the technology has evolved and become increasingly complex, but also that they may not own the intellectual property (IP) that new digital technologies are built upon. In this fast-changing digital world, they face a fundamental problem: their power base is built on traditional business models and ideas that are in danger of becoming outdated and diminished. Many firms have built huge value into intellectual property portfolios for those traditional models, which are in danger of being displaced by disruptive new approaches.

Driving change

The automotive sector is a case in point. It is likely that in a decade cars will mostly be powered by electricity and electric engines, and that these vehicles will be more 'intelligent', if not autonomous. Such changes are enticing different kinds of companies into the sector, including established digital giants, posing a whole new challenge to traditional automotive manufacturers. These transformations in automotive come with an enormous IP risk for incumbents. Two significant risks arise: First, the firms that dominate the automotive sector of the future are likely to be those that actually own the IP for the emerging technologies, or key elements of them. Knowing how to use them is insufficient. If this know-how belongs to digital giants entering the sector, it could mean that traditional automotive manufacturers need to forge partnerships in order to survive, and end up paying for access to the technology. Second, those large automotive companies that have dominated the sector for years have built patent portfolios around the technologies relevant for the current (or previous) business model. Those portfolios are in danger of becoming seriously devalued.

Five IP challenges in a digital economy

Manufacturing firms face several challenges around IP in the digital economy, including the following five:

1. Protecting and exploiting the value of data

There is increasing value held in the large volumes of data being accumulated within companies. In addition to product sales data, customer records, component prices, supply chain information or market statistics, there are commercially sensitive electronic items such as CAD drawings. Such data presents an IP risk in terms of potential breaches of cyber security.

Of particular value are proprietary cloud-based algorithms and large scale training data repositories collected over time through Internet of Things (IoT) devices. Artifical Intelligence (AI) algorithms increase in value as they gather and use training data to improve their accuracy. In a digital economy, such proprietary and extensively-trained AI algorithms can be highly valuable, potentially even contributing a significant share of a firm's value.

Consequently, companies need to pay close attention to protecting and exploiting this value. In the past, IP security was focused on retaining knowledge held by people within the workforce, using tactics like contractual clauses to prevent people leaving the company and joining competitors. While this may in many cases still be relevant, the focus is shifting towards cyber security for protecting data.

Additionally, to boost the value derived from data, companies will find it increasingly attractive to consider licensing out their data.

Dr Frank Tietze

Digital rights management then becomes crucial. They could take a conservative approach to this, working restrictively with a small number of parties within their supply chain or ecosystem, or take a more expansive approach which could even extend to licensing data to competitors. Digital ledger technologies, such as blockchain, are likely to play an important role for protecting but also the commercializing data and IP.

2. Moving to portfolio-based IP

It is vital to understand the power of IP portfolios. In our example of the automotive sector, electronics-based technologies relevant for future vehicle manufacturing could include the IoT, AI, battery management and drone control. Successful companies will be those that understand how to develop large and strategically-driven IP portfolios covering multiple relevant, emerging and converging technologies.

They will also need to have (or to access) the complementary knowledge and skills in order to find and develop favourable trajectories that lock-out competitors.

If new entrants such as digital giants can do this successfully, and early, they could gain a competitive advantage against big incumbents that may find it difficult, if not impossible, to catch up and close the gap.

3. 'In-licensing' and 'out-licensing': needs and opportunities

Given the complex and fragmented patent landscape of the digital economy (with IP ownership distributed across many firms), it will be difficult for companies to own all the IP necessary for manufacturing intelligent devices. As a result, companies will need to consider how best to acquire usage rights from IP owners. Often they will need to sign in-licensing contracts to achieve compliance before product launch and to avoid infringements.

On the flip side, the proprietary technologies which manufacturers own might be of value to other companies who would be willing to pay for accessing those technologies. However, setting up out-licensing services requires specific and scarce skills and capabilities, which companies will need to invest in if they wish to pursue this opportunity.

4. Understanding the true cost of 'free' software

Manufacturing firms develop software components built into digital products internally, but may also utilize existing 'free' and open source software obtained from leading development platforms such as Github. What may not be immediately apparent are the total cost implications of open source software: often use is 'free' only under certain conditions, such as requiring the user to make all software developed on an open source component freely available to the community. Manufacturing firms will have to understand and master the complexities, differences and requirements of the numerous licensing types for compliance reasons. Already some large consulting companies have found a good business model providing compliance services to companies using open source software, for substantial fees.

5. Managing trade secrets

We are currently seeing a tightening of legislation around particularly important proprietary company knowledge typically referred to as trade secret, which again could include well-trained AI algorithms. This will require firms to identify and separately treat, protect and enforce their most valuable know-how / data (trade secrets) from their generic data (such as customer records).

Strategies for IP in the digital economy

In order to be well-positioned and prepared to succeed in the digital economy, there are three central pillars for manufacturing firms to consider for managing IP. The first is about **people**. Firms will need to possess or access the IP awareness and IP management capabilities necessary to succeed in the digital economy.

The second concerns **business objectives** and structures. Any good and forward-looking IP strategy needs to be aligned with organisational structures and business objectives. This may require consolidation of existing IP management, which is often scattered across multiple departments: for instance, while technologies may be managed within patent departments, brands may be dealt with by marketing departments, trademarks by legal teams, contracts by a purchasing department, and software and data within IT.

The third is **strategy**. Organisations need to develop their own integrated digital IP strategy. This is likely to be substantially different from a traditional IP strategy: it needs to consider the different types of IP, including software and data as well as the firm's approach to in- and out-licensing, and involve a portfolio approach in which multiple IP assets complement one another.

Ultimately, the success of manufacturers in the digital economy is likely to hinge on having the know-how to develop an integrated portfolio-based IP strategy, and to align it with broader organisational goals and structures.

Student insights

Can haptic gloves make it easier to learn a skill?

Interview with Ben Proyer

Ben Proyer has just completed the IfM's MPhil course (ISMM), and is now at the IfM as a visiting graduate student. He has been part of an IfM research team testing the effectiveness of haptic gloves and virtual reality technologies for industrial skills development. We spoke with Ben to gain his perspective on the project.

Please tell us about the recent project and what you were trying to find out.

I've been working as part of a team with Thomas Bohné, Lukas Hysky and Andreas Leubner to better understand how wearable technologies could be used and applied in industry. Most recently this involved an experiment in which participants had to learn a new skill wearing haptic gloves to find out how the technology affects their performance, compared with participants who learned the same skill using conventional methods.

We know that many companies are exploring these technologies, and some are already investing a lot in virtual, augmented or haptic technologies for training purposes, but there has been very little research to compare the effectiveness of these new technologies with traditional methods of learning new skills.

What are haptic gloves?

Haptic gloves give your hands feedback information – this could be through vibration or force or other sensual feedback. Some gloves even have air bubbles that can be pumped up to give specific sensations, such as feeling a spider walking across your hand.

We've been working with gloves that give vibration and force feedback. If you grab an object like a mug in virtual reality, the gloves hold your fingers in place so it really feels like you're gripping something. Virtual technology is being explored for lots of potential purposes including use cases in manufacturing, the military, aerospace or surgery. There is tremendous scope for what it could offer, because it can simulate any environment without huge costs or any danger.

What did the experiment involve?

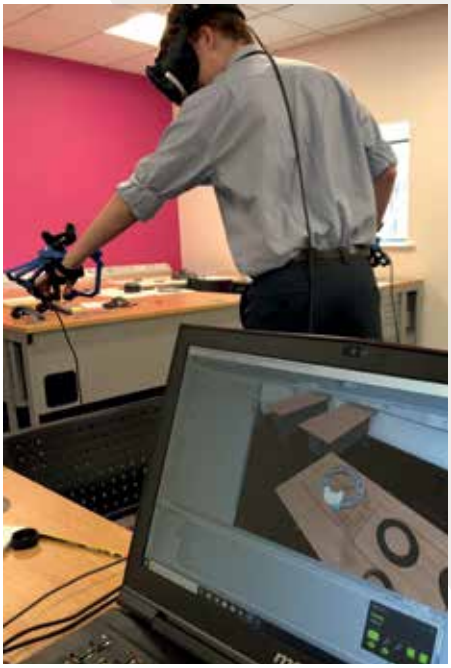
We were based for two weeks at EEF's Technology Training Centre in Birmingham, working with 140 apprentices and around 100 members of staff with different backgrounds, ages and experience. Participants were taught a new skill – the assembly of a tractor clutch provided by John Deere – using three different approaches. The first group was asked to follow paper-based instructions. The second used virtual reality technology with two controllers and a headset – a 'standard' consumer-grade version that is already sold in shops. The third group used haptic gloves with force-feedback and a headset. Then all of them had to perform the same clutch assembly task in reality with a real clutch and we measured and compared performance across the three training methods.

What did you find?

We are still analysing the data as we just finished the experiment, but our preliminary analysis indicates that the group using the commercially-available VR headset and controllers had a slightly stronger performance after the training.

However, we are also aware that various factors may be at play and influencing this. Haptic gloves are still in their infancy in terms of technological development. Participants using the gloves had to get used to them while also focusing on the assembly process. As this technology improves, we can envisage that it will become easier to manipulate things in virtual reality using the gloves, and the value for training purposes may improve.

It is important to start building a better research-based understanding of how such technology can help already, and keep measuring improvements over time as the technology progresses. We also want to research the effectiveness for different types of tasks, as this also plays an important role.



From a personal perspective Ben, what did you gain from being involved in this project?

It was great to be involved in a research project and a large experiment with people who actually need to access training methods for industrial skills. We had a wide range of people, all ages, including people who didn't have much experience of using computers! Most participants really engaged with what we were doing, and we received some really positive feedback.

It was amusing at times to see people's behaviour in virtual environments – things like trying to put the real controllers down on a virtual table, it was funny to watch!

I learned a lot about project management too. There were quite a few challenges in coordinating different research partners and companies, including some technology start-ups, and we had some bottlenecks.

I've enjoyed this whole experience and I'm considering whether to stay in research.

STIM Consortium

The Strategic Technology & Innovation Management (STIM) Consortium is a practice-oriented research and networking collaboration between industrial member companies and the Centre for Technology Management.

We are launching the next year's annual programme on 22nd November 2018. If you are interested in attending this event, or finding out more about joining the STIM Consortium, please contact Dr Robert Phaal rp108@cam.ac.uk or visit www.ifm.eng.cam.ac.uk/research/ctm/stim.

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