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# From 'Cool Science' to Changing the World

## The Opportunity to Support Pre-startup Science Commercialization through Ethnography and Human-Centered Design

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*Introducing an emerging context for human-centered design work, this paper extends previous EPIC literature on startup innovation upstream into university science commercialization. It provides new perspectives on how the human-centered design community can engage with scientific models of agency to inform broader engagement with the innovation and design challenges inherent in 'intelligent' technologies, and offers the challenge of engaging with and developing empathy for the dispositions of scientist innovators as a new vantage point from which to reflect on our core strength as facilitators of cross-disciplinary collaboration for innovation and design.*

## INTRODUCTION

The project to engage with and humanize the culture, practices and outputs of technical disciplines (particularly computer science and software engineering) has been at the heart of the work of practitioners in the human-centered innovation and design community from the beginning. (Cefkin 2009) This paper addresses itself to a relatively new chapter in this project, as human-centered design practitioners are drawn more into engagement with science and scientists because of the increasingly significant role of science-driven emerging technologies in mainstream product and service experiences (AI, genetics, etc.), and the increasing centrality of university-based science to the industrial base of Industry 4.0 (Pollitzer 2019)

The successful propagation of human-centered innovation and design further upstream in Industry 4.0 innovation processes faces both structural and cultural challenges. Recent EPIC conferences have heard about opportunities for ethnography and human-centered design to bring more 'meaningful innovation' to the startup sector, but also that the metrics-centric cultures of Lean Startup and Silicon Valley venture capital constitute barriers to such a change (Haines 2014; 2016; Ries 2011). This paper's focus goes one step further upstream than Haines, to look at how science innovation happens pre-startup.

In science innovation, moving from pre-startup to startup innovation usually means moving across the boundary between the university and the world beyond. This boundary is both a profound conceptual one, rooted in several centuries of scientific discipline formation (Schaffer 2010), and frequently also a physical one, with commercial startup activity taking place in science parks located around the periphery of university campuses.

We argue that whilst the contribution that the human-centered design community can make to providing and building innovation and design skills and capability within the startup and pre-startup science community is crucial, a more important opportunity lies in the human-centered design challenge of engaging with and understanding scientists and science culture - the motivations, dispositions and skills they bring to their innovation and commercialization efforts – to define how best to support them in contributing more effectively to the wider innovation processes in which their work plays an increasingly important part. (Stuart & Ding 2006)

This paper's co-authors have engaged in this challenge from opposite and complementary directions: one as a serial technology entrepreneur who now runs a technology commercialization program for students and scientist 'inventors' at Cambridge University in the UK; the other as a business anthropologist and human-centered design practitioner who has worked with major global product companies to optimize their innovation processes, from science-based R&D through to product strategy and design, and who has introduced human-centered design approaches to the curriculum of the same university technology commercialization program.

Drawing on over 12 years experience of working in university pre-startup science commercialization, we present a detailed ethnographic analysis of a program designed to facilitate culture translation between the worlds of academic science and commercial application. This program brings together scientist 'inventors' with teams of student and early career scientists on projects to identify potential paths to application and commercialization. Projects aim to provide a microcosm of the startup experience, and can be seen as a form of participant ethnography, engaging with a wide range of participants in the university startup ecosystem, and with potential users and stakeholders in the world beyond.

We describe the journey that project team-members make in terms of shifting notions of scientific agency, from enchantment with the 'cool science' they are keen to get the opportunity to work on at the beginning of a project (Gell 1998), to gradually embracing broader socio-technical systems and cultural contexts (Latour 2005) as they formulate plans to bring positive impact into the world.

We consider the balance between enabling rapid adoption of templated research and design tools, and nurturing and developing the creativity, problem solving skills and dispositions that team members bring from their scientific education and experience.

We conclude by presenting a model of the motivations, skills and dispositions that scientists bring to innovation and commercialization, as an invitation for further engagement by the ethnographic research and human-centered design community.

## BACKGROUND: SCIENCE AS INNOVATION

This paper is written from the perspective of practitioners, with the objective of promoting collaboration between the two communities of practitioners to which the authors respectively belong – science commercialization and human-centered design. In this context, our exploration of how scientific research leads to innovation has primarily a practical objective – that of enabling human-centered design practitioners to collaborate more effectively with scientist-innovators by comparing how innovation happens within the context of pre-startup science commercialization with the best-practice expectations of commercial innovation. We thus take our definition of 'innovation' from the context of human-centered design, as a practice which addresses relevant and meaningful problems in people's lives by designing solutions delivered through products or services. We frame our investigation in this way to allow us to explore the affinities between scientist-innovators and human-centered design practitioners in their projects to both understand and change the world.

From our practitioner perspective we do not aim to engage directly with debates about the nature of scientific knowledge production that have been developed within the fields of the philosophy of science and STS (science and technology studies, or science, technology and society) – but those debates provide important context for our discussion. Kuhn noted the processes whereby scientists' worldviews are shaped by rigorous training via 'exemplars' to the currently dominant scientific paradigm (Kuhn 1962). Our scope goes beyond the processes which recruit scientists into the disciplines in which they work, to look at how they negotiate their own balance of career success and impact within science with other possibilities for impact outside it resulting from the application and commercialization of their work. A similar difference of scope is evident if we consider how Hélène Mialet, talking about Popper, draws a distinction between, "the context of discovery (the realm of imagination) and the context of justification (the realm of logic and method)" (Mialet 2012: 457). The journey that we describe in this paper starts with the context of discovery and imagination, but moves beyond the legitimization of scientific discovery within academic science in the realm of logic and method, to look at the thread which links the initial discovery to its potential for application and commercialization.

The ethnographic data that this paper is based on is structured around the journeys of individual scientists, in their science careers, and in their experiences of the commercialization of science. This may appear at odds with the shift in STS, initiated by Bruno Latour's Science in Action, from a focus on scientists and science culture towards ethnographic investigation of how science works in practice through the operation of networks not only of people but of the objects and technologies with and through which they work (Latour 1987; Martin 1998). But, whilst our focus on individual scientists' journeys is primarily a methodological device to draw out comparisons between innovation processes in scientific and commercial contexts, we do also see it as being in line with the position taken by Hélène Mialet's reframing of Actor Network Theory in her investigation of innovation careers in an international energy company (Mialet 2009):

> …if we pay careful attention to science in action, we can see at the centre of a web of practices, collectivities and technologies, an individual who acts, that is, who 'creates'. I call this actor the distributed-centred subject. I argue that the more this actor is linked up with his institution, his objects of research, his co-workers, etc. the more potential he has to become inventive: and the more inventive he becomes, the more he seemingly distinguishes himself by his singularity as an inventor. (Mialet 2009: 257)

The scientists whose innovation journeys we explore in this paper take on the challenge of being inventive in the sense defined by Mialet – but in multiple contexts: basic science research; application of science; and commercialization. Each of these contexts involves different constellations of disciplines and practices, of organizations and institutions, and of instrumental and mediating technologies. The challenge for human-centered design practitioners is to map out what is required for scientists to successfully navigate these contexts whilst bringing a human-centered focus to their innovation efforts.

## Changing relationship between academic science and commerce

The occasion for this paper, as for EPIC's 2019 theme of Agency, is our contemporary sense of living in a historical moment in which science-driven technology innovation - through a confluence of computer science, genetics, and materials science - plays a uniquely critical role in the fate and future of humanity. For our purposes of understanding the culture and institutional forms of science as innovation, it is interesting to look back to the period during the twentieth century when the structural relationships which still underpin the relationship between science and commerce became entrenched. The British novelist and physical chemist C P Snow, writing in the late 1950's, characterized it thus:

> I believe the industrial society of electronics, atomic energy, automation, is in cardinal respects different in kind from any that has gone before, and will change the world much more. It is this transformation that, in my view, is entitled to the name of 'scientific revolution'. (Snow 1959: 31)

The period that Snow was describing, in the aftermath of the intense science-driven military-industrial competition of the Second World War, was one which saw a major shift towards governments attempting to shape the basic scientific research agenda to the needs of national military and industrial strategy. Close relationships were established between science departments at research universities and military and industrial R&D labs – relationships in which science labs delivered basic science discovery and R&D labs delivered innovation (Powell & Sandholtz 2012: 385).

The emergence of the first genetics-driven biotech university spin-outs in the US during the late 1970's and early 1980's initiated a process of transformation in this relationship. The traditional divide between university science and commercial innovation has been increasingly supplanted by what Walter W. Powell and Kurt Sandholtz describe as, "interdependent and collaborative knowledge development spanning both public and private organizations," as, "biotechnology forged a recombination of scientific and commercial cultures, which led to the creation of new organizational practices and forms of discovery." (Powell & Sandholtz 2012: 386; Flink and Kaldewey 2018: 257)

Forty years on from that first biotech revolution, the hybrid of science, commerce and finance described by Powell and Sandholtz is a vital and integral component of the science and technology commercialization ecosystems which have formed around leading research universities around the world. But though university science has become increasingly integrated into commercial innovation processes and agendas, innovation within universities remains very different to commercial innovation. The aim of this paper is to provide a guide to those differences for human-centered design practitioners coming from the world of commercial innovation. So in what ways might science innovation not conform to their expectations?

The first difference that a commercial human-centered design practitioner might notice when trying to identify how science innovation happens in the university context would be in terms of process. The same forty years that has seen the rise of startup ecosystems around universities has seen commercial innovation transformed around the imperative of human-centered design, and along with this has come a convergence around a best-practice process for innovation, the underlying principles of which are deployed within branded product and service companies across almost all product categories and industry sectors. Making people's consumption experiences in-context the organizing principle, the widespread adoption of this best-practice process within commercial innovation practice – exemplified by the five steps of Design Thinking: Empathize, Define, Ideate, Prototype, Test – has been driven by intensifying market competition, shortening product and service renewal cycles, and pervasive digitization. As a result, commercial innovation processes have become increasingly rational, organized and integrated, aligning functions and objectives across companies.

By contrast, science innovation is discontinuous, cultural, and fragmented. Unlike commercial innovation, it is not organized under a single imperative or objective. Science innovation happens through the overlapping of a set of related, but separate interests and objectives. These are distributed across complex ecosystems, whose key elements include: academic science departments; university technology transfer offices; business, design and engineering departments; student societies; and university and commercial startup incubators and accelerators. From the perspective of mainstream innovation best practice, as the 'front end' of the emergent Industry 4.0 innovation process, pre-startup science innovation might be expected to involve an open exploratory market or contextual discovery phase. This is largely absent from the current science innovation process, whose primary focus, of course, is on science discovery rather than problem or opportunity discovery. A key objective of this paper is thus to explore the conditions for science innovation to include effective problem or market discovery.

## APPROACH

This paper is based on the authors' auto-ethnographic analysis of their experience in the science and technology commercialization ecosystem in and around Cambridge University in the UK. Following a successful career as an entrepreneur in technology startups, in 2006 Amy Weatherup set up i-Teams, a program for pre-startup science commercialization, based in the University's Institute for Manufacturing, and serving the whole of the University[1]. The program consists of projects which run for ten weeks over the course of an academic term, bringing together scientists with potentially commercializable ideas with teams of post-graduate scientists to define whether or not there is a viable commercialization path (Moktar 2018). In the period during which Amy Weatherup has run i-Teams since 2006, it has hosted over 150 projects - in which over 1000 students have participated - and generated over 70 startup companies. Simon Pulman-Jones joined the i-Teams program in 2012 as a project mentor, and since 2015 has run Design Thinking workshops as a component of the i-Teams curriculum.

In addition, twenty ethnographic interviews were conducted with previous i-Teams participants during June and July 2019, exploring their experience in science innovation from the start of their science education, through their experience on the i-Teams program, to their ongoing experience in science commercialization. This sample covered a range of experience, including scientist-innovators who have generated spin-out companies but remained in academic science careers, others who have moved out of academic science and gone on to found and run startup companies, and post-graduate scientists from a range of disciplines.

## COOL SCIENCE: SCIENTISTS AS INNOVATORS

In her introduction to Ethnography and the Corporate Encounter, Melissa Cekfin writes of, "the drive anthropologically oriented researchers feel to work deep within the engines of the business sector." (Cefkin 2009: 2) In this section of the paper, we explore what drives scientists to become involved in the application and commercialization of their basic scientific research, and their experience of that journey. From the perspective of the potential for collaboration between human-centered design professionals and scientists, it is interesting to note the similarities between their motivations and dispositions – particularly in relation to becoming engaged with business.

### Scientists' innovation journey

The term, 'cool science', is often heard in connection with i-Teams projects. In the first instance the prospect of being able to work with 'cool science' motivates students to participate in the program. And the coolness of science was also something that many of the i-Teams participants that we spoke to talked about as what motivated their initial interest and involvement in science. In this section we explore how scientists make the journey from their first involvement in basic science through to becoming engaged in commercialization: what leads them, usually in the absence of any formal objectives or process, to follow this path.

*Stage one: engagement in basic science research*

The dominant theme when our i-Teams science-innovators talked about what first motivated their involvement in basic science research was creativity and imagination – frequently framed around a heightened visual sense of entities, structures and phenomena unfolding in three-dimensional space.

One of our research participants, a molecular biologist, talked about why she was attracted to the work of the lead scientist whose team she aimed, successfully, to work on after completing her PhD: "It was novel. It was imaginative. He managed to turn the field around a few times during his career. He will embark on risky stuff that no one else is doing. He's just driven by his interest and is not afraid of jumping into something that might give fruit or might not." The way in which the work was imaginative became clear from her description of one of the team's main discoveries:

> We were doing a lot of fluorescence in situ hybridization. That's detecting genes, all their transcripts, in fixed cells under the microscope. You can see shiny dots to detect various relationships between molecules in the nucleus. And we just by chance encountered the phenomenon that genes came together when they were being active. They were just very close in 3D in the nucleus. If you're detecting one gene and another gene in two different colors, in many cases in the cell they were on top of each other – one green, one red, making yellow. So we started looking into this because we thought, that might be because there is a 3D architecture of the nucleus that is important for how transcription in the nucleus functions.

Here we see some key characteristics of science-innovators that are of interest from the perspective of human-centered design practitioners interested in engaging with science innovation. Firstly, we see the intensely visual nature of the scientific imagination. (Ihde 2000) In this case, a technique which caused molecules to fluoresce in different colors when viewed under the microscope revealed an unexpected relationship between when genes became active and their position in 3D in relation to other genes. The scientist is primed to recognize when something 'looks' different to what existing knowledge and models of the phenomena would lead one to expect. Their attention is focused, as it were, at the periphery of known patterns – looking for anomalies which might signal a disruptive innovation in scientific knowledge. In this case, this visual observation led to important discoveries about how genes operate and organize themselves within the nucleus, which in turn has powerful implications for optimizing how drugs can target diseases. Secondly, we see the extent to which basic science is dependent upon and driven by technological innovation – in this case the fluorescence approach which made the phenomenon of 3D gene architecture evident. (Ihde 2009: 34-35)

The example above dramatizes the extent to which scientists are expert observers. Basic science knowledge and hypotheses form the base context for their work, but the substance of the daily work of experimental science is an embodied process of registering significant patterns and anomalies (using the observer's body as the the primary instrument), mediated by technologies (in this case the lab, the microscope and the fluorescence technique). And here we might start to recognize affinities between scientists as practitioners and human-centered design practitioners. Science practitioners are on the one hand embodied participant observers (ethnography) and on the other artisanal manipulators of technology (design).

What makes 'cool science' cool is this combination of delightfully complex configurations of phenomena in new and unexpected patterns, and the scientist's sense of involvement at the heart of that delight as the registering and recognizing imagination. This constitutes stage one in the scientist's innovation journey, anchoring her engagement in basic science.

*Stage two: from basic science to application context*

Our purpose is to follow the thread of motivation and rationale that leads scientists beyond their engagement in basic science research towards something which might in the end have impact in the world outside of academia. This next step is a small one, but an important one, as it is the step which involves reaching out beyond the lab. We can pick up the 3D gene architecture example above to unfold the rationale.

The team had identified that parts of the genome came together in 3D space in the nucleus when the genes were active and regulating gene output. They had identified a previously undiscovered phenomenon, but that identification was of no value in itself without an understanding of why it happens. In this case, the only way to discover what this 3D mobilization of genes was doing was to leap out of the context of the lab and make reference to a Genome Wide Association Study. Genome Wide Association Studies link genetic variants with large populations of individuals for the purpose of identifying associations between genetic variants and individual traits. This would allow the team to identify whether the gene configurations which they had observed in the lab could be linked to any diseases or other traits in the human population.

This is the first small step along the path from basic science to application and commercialization. It involves identifying a context in the world where the effects of the scientific phenomenon in question might be located or identified. As such this is very much application with a small 'a' – as the primary focus is not on the application context in the world, but rather to use that application context to validate hypotheses about scientific phenomena observed in the lab.

But this small step is often the one at which the scientist-innovator's imagination is captured by the prospect that the discovery that they have made in the lab might be able to do something out in the world. Some of our participants talked about their investment in their 'cool' basic science discovery being like that of a parent's investment in children. Up until that point they had not expected the focus of their work to extend beyond basic science. But now a mixture of curiosity and pride drove them on to discover what their 'offspring' might be able to do to make a positive contribution in the world.

*Stage three: from application context to potential impact*

For many scientists, in many fields of science, it may be sufficient for them to stop at the previous stage, in which they have engaged with an application context in the world in order to return back to their basic science context in the lab with knowledge that allows them to progress their basic science agenda. Pressure to publish within their field may militate in favor of this, with little incentive to explore application potential in the world further.

But many scientists, of course, do make the move from identifying an application context to exploring potential for their new scientific knowledge to have impact in the world. The experience of one of our i-Teams scientist-innovators provides an example. He is a chemical engineer who runs a team of scientists at Cambridge University working on metal-organic frameworks. The metal-organic frameworks are of scientific interest because of their capacity to capture and absorb other molecules within their complex molecular structure. In effect they can function like extraordinarily powerful sponges. The work of the team is primarily focused on advancing basic scientific understanding of this phenomenon, though the ability of new materials to absorb large volumes of other liquids or gases has evident practical application. It was an accident which opened up the possibility of significant impact in terms of practical application in the world.

One member of the team was conducting a series of experiments in the lab to test the absorbency capacity of different metal-organic compounds. This involved trays of samples of the compounds being left in ovens overnight to dry, to finish them before testing. The scientist returned the following morning to discover that he had forgotten to put one of the trays in the oven, meaning that it had spent the night in the open on the bench. He called in his boss to tell him. The team leader noticed that the compound that had been left out of the oven had dried differently, forming a smooth-surfaced pellet rather than a powder. Intrigued, he organized tests of the absorbency of the pellets, and much to his surprise it turned out that it was a factor of ten greater than what would be expected. In this case the technical advantage was so great that the potential impact across a range of industry sectors and application areas was immediately apparent, and the innovation process moved on to patenting, validation of potential application use cases, and eventually to formation of a spin-out company pursuing applications ranging from bulk gas transportation to drug delivery.

In this case the path from basic science research to potential application impact was unexpected, but relatively straightforward when it presented itself. A ten times performance advantage is what is generally held to be required if a scientific-technical advance is to have a chance of being viable in market once investment and time to market are taken into account.

This is the stage at which the science innovation process becomes more dependent upon chance contingencies. At the previous stage, the scientific literature will provide the link to application contexts in the world, with which to validate experimentally derived hypotheses. At this stage the process is more dependent upon the scientist's acquaintance with performance benchmarks of scientific technologies in application in the world. Startling leaps in technical performance, as in the above example, may be sufficient on their own to prompt exploration of patent potential via the university technology-transfer office, but often this will not be the case.

There are many areas in which performance advantages of new scientific technologies in real-world applications can be hard to judge. Drug discovery is one such area, in which novel approaches to combatting the mechanisms of diseases may offer theoretical potential which can only be fully tested after a long process of clinical trials. In this case, what motivates scientists and the teams who become involved in commercialization efforts is strong and detailed understanding of the significance and potential value, in both human and market terms, of the need which could be addressed.

Whilst medical science may involve this intrinsic element of human-centricity (Schwartz et al 2016), there are many areas in which science innovation does not have such a direct link to meaningful problems in the world – areas in which if a new scientific technology does not have an immediately apparent gross performance advantage, potentially valuable opportunities for impact in the world may go unaddressed. It is therefore at this point in the science innovation process that there is the most striking divergence from commercial human-centered design best-practice - which puts meaningful problems in the world at the heart of the process.

This problem is recognized within the university sector, and addressed in a range of ways, including, but not limited to: educational courses and curricula addressing areas of application relevant to a given discipline; research funding calls by government funding bodies focused on marshaling multi-disciplinary responses to deliver impact against specific problem agendas (Shneiderman 2016); institutes or centers established within universities whose aim is to raise awareness and mobilize university assets (research, intellectual property, etc.) around problems in specific domains or topics (Rogers et al 1999); knowledge-transfer offices which facilitate external access to university expertise; student clubs or societies mobilizing activity around specific areas of interest or policy agendas.

These activities constitute the rich and complex informal system through which the university sector's potential impact in the world beyond the academy is mediated. As a relatively informal and unstructured system it is highly dependent upon the personal experience and social networks of individual students and academics to make connections between potential solutions generated within the academy and relevant problems out in the world.

Analysis of the effectiveness of university systems in aligning university knowledge creation with potential areas of impact in the world is beyond the scope of this paper. What we are able to address is the experience of scientist-innovators as they pursue their careers within this system. Our experience through the i-Teams program, and our research on the career experience of scientists who have participated in the program, bears out the extent to which making links between potential solutions generated in the course of basic science research and relevant problems in the world is highly dependent upon chance and contingency. (Indeed i-Teams is designed as an approach to make these links in a more systematic way.) The experience of many student participants in i-Teams is that they remain unaware of the potential for the scientific knowledge and expertise which they are developing during their studies to be harnessed through innovation and commercialization approaches to solve problems in the world, until they arrive at a junction in their educational or academic career which prompts them to investigate options for the next step in their career.

## CHANGING THE WORLD

We have traced the journey scientist-innovators make from their first enchantment by the coolness of science through to the realization that their scientific ideas may have the potential for impact in the world beyond academic science. So far, we have framed this journey from the perspective of the individual scientist's investment and involvement in scientific exploration and discovery. The central role of the individual scientist in university-based science innovation is one critical way that science-innovation differs from commercial innovation, which is something that we will return to later in the paper. At this stage, though, we want to bring a different frame to the discussion – that of agency.

Scientists who become interested in pursuing the potential impact that their ideas can have in the world inevitably find themselves confronted by making the transition from changing science, to changing the world. In this section of the paper we will chart this journey in terms of different fields of agency, through the unfolding of a pre-startup science commercialization project on the i-Teams program.

### The science commercialization journey

The i-Teams program at Cambridge University was launched in 2006 to address a gap in pre-startup science commercialization provision at the university. No provision existed at the time for post-graduate students who did not yet have an idea for a startup company to gain exposure to science commercialization approaches. Existing science and technology commercialization and entrepreneurship support within the university was predominantly in the form of business plan competitions, incubators and accelerators. These assumed that those entering the competitions or programs already had an existing startup business concept as their starting point, thus excluding many post-graduate students who were at an earlier stage of exploring science commercialization. From the outset, therefore, the i-Teams program placed itself further upstream in the innovation process. Whereas the business plan competitions, incubators and accelerators are focused on taking a startup idea, getting it into shape and making it work, i-Teams focuses on the key question of whether or not a viable commercialization path exists and is worth pursuing.

i-Teams projects are rooted in a symbiotic relationship between two stakeholder groups: post-graduate students looking to learn about science commercialization, and scientists (known within the program as 'inventors') whose new scientific technologies provide the basis for the projects. The post-graduate student teams get the experience of working with leading-edge scientific technologies and learning about the realities of exploring and defining commercialization paths; whilst the inventors benefit from the focused work of a capable and committed team of young scientists to uncover new opportunities for their technologies to deliver impact. The inventors also have access to learning by interacting with the student team as the project develops - some choose to benefit directly from this to increase their own skills and knowledge (these are usually the ones thinking of making a more active transition out of academia), while others treat it more as an external consulting project with results delivered to them at the end (these are usually the ones dedicated to an academic career path). Projects therefore aim to provide both a valuable learning experience for the post-graduate students, and a successful outcome for the inventors in terms of clarification about the commercialization potential of their ideas. The balance between these twin project objectives is overseen by project mentors. Mentors are chosen for projects based either on their experience of commercializing similar technologies in related industrial sectors, or on their experience in running innovation and commercialization projects – or a combination of both.

Projects represent a significant time commitment for the team members. Over the course of ten weeks, the teams convene for lectures and working sessions one evening per week with the mentor and the core i-Teams staff, and co-ordinate significant amounts of both team and individual work 'offline' between those weekly meetings to conduct research, fieldwork and analysis. Participation by the inventors varies, with some attending all the weekly meetings with the teams, and others joining only for key milestone meetings at the beginning, middle and end of the project. There are three different i-Teams programs which run in parallel, each with a different focus: Innovation i-Teams, Medical i-Teams and Development i-Teams[2]. Each of these programs comprises three teams of seven student team members. Interaction and learning across the three teams, as their projects develop in different ways, is an important component of the program.

*Experiential ethos: challenging the certainties and structures of university science with the complex realities and uncertainties of the outside world*

The ethos of the i-Teams program is determinedly open, flexible and experiential, as opposed to didactic, instructional and templated. It seeks not to provide theoretical training in science commercialization, but to expose both team members and inventors to its realities. A structure of objectives and milestones is provided for the project, but teams are largely left to discover for themselves how best to organize and manage their efforts.

Project outline:

1. Inventors introduce their technologies to their i-Team. Teams interrogate the inventors to ensure they understand the technologies in terms of technical characteristics and performance, unique intellectual property (IP) and benefits insofar as the inventor currently perceives them.
2. Teams brainstorm as broad as possible a range of potential application areas for the inventor's technology.

3. Teams cluster and prioritize potential application areas and assign tasks within the team to research technical and business viability and stakeholders to approach.
4. Teams contact relevant stakeholders (academic and industry experts; B2B or consumer end-customers, etc.) and conduct interviews and/or fieldwork.
5. Teams refine value propositions for the technology and develop commercialization recommendations and roadmap. This may also include identifying technical milestones that need to be addressed before commercialization efforts can proceed.
6. Final presentation of commercialization plans to members of the Cambridge innovation and investment community.

This process unfolds over the ten week period of the project, with the team's work loosely guided by the mentor. Steps 3, 4 and 5 are largely iterative, as teams continually develop and revise their hypotheses and value propositions.

The weekly evening sessions for the project consist of team working time and lectures and workshops given by experts in technology commercialization and innovation. Though the topics covered in the lectures and workshops are intended to be relevant and useful for the teams in supporting their work on their projects, they are not directly instructional, and they do not provide structured, templated processes or tools to be used by the teams. The intention, rather, is to expose the teams to the underlying principles and realities involved in science and technology commercialization and also to expose them to different areas of professional expertise and experience. Rather than being trained – provided with a set of skills and tools tailored to the task in hand – the i-Teams members are offered the opportunity to become acquainted with the world of science and technology commercialization and to be inspired – or not – to pursue it further in their careers.

This open-ness is at the heart of the i-Teams ethos, and an important aspect of the program's objective to provide a microcosm of the startup experience within the ten week capsule of the project. In contrast with other types of pre-startup commercialization provision, which work towards fixed deliverables such as the business model canvas or a startup pitch, the i-Teams program is agnostic about project outcomes and deliverables. What might seem like a negative outcome – where a team identifies that there is no viable commercial opportunity for the inventor's technology (because its benefits are not relevant and compelling, or because similar or better solutions already exist) – is a very useful outcome both for the inventor, who may be able to revise and adapt their solution, or re-focus their efforts in other areas, and for the post-graduate student team members, who learn the difficulty of achieving all of the criteria required for successful commercialization, and the value of identifying weaknesses in value propositions at an early stage in order to re-focus scarce resources.

The open, experiential nature of i-Teams projects can be seen as a form of participant ethnography. Indeed, one of the core objectives in the design and running of the i-Teams program has been to enable culture translation between the world of academic science and the world of technology commercialization. i-Teams participants are exposed to new cultural contexts – from technology commercialization professionals and their practices, to the realities of startup team formation and collaboration, to industry experts and processes, and to consumption contexts in which their assumptions and value propositions are tested – and they go through the experience of making sense of those new cultural contexts in much the same ways that an anthropologist or ethnographer does in the course of their fieldwork – by registering new terms, new concepts, new language, new practices in relation to their existing cultural frames of reference and figuring out how to translate them.

*Encountering new fields of agency: the i-Teams project journey*

We have outlined the i-Teams project process in terms of its high-level objectives and milestones, and now turn to examine the process from the perspective of the different fields of agency with which the team members become acquainted as the project unfolds.

*Phase One: Cool Science Enchantment*

If the i-Teams project experience can be seen as an ethnographic encounter with the realities of science and technology commercialization, with the project being a liminal space between scientific and commercial cultures, the start of the project takes place firmly within science-culture. The first evening session involves a presentation by the inventors to their teams about the new science-technologies they hope to commercialize, with team members invited to interrogate the inventors about their technologies. It is made clear to the teams that it is crucial that they understand not just the technical, scientific details of the technology, but also the ways in which those technical features and characteristics could translate into benefits of relevance in potential contexts of use. Despite this injunction, there is usually a significant pull at this stage in the project towards detailed discussion between the team and the inventor about the technology in purely scientific, technical terms. Of course, this is both understandable and necessary, as the teams need to be confident that they properly understand the scientific and technical foundations of the technologies that they are working with – and that they will need to discuss with a range of expert and non-expert stakeholders later in the project. But the gravitational pull of purely scientific discussion at this stage of the project can also be seen as a result of the power of the science culture to which the inventor and the team members belong[3], and to the model of scientific agency at the heart of that culture[4].

To understand how this model of agency plays out within the interactions and discussions of the team at this point in the project we can return to the earlier example of the discovery of new ways in which parts of the genome mobilize in relation to each other in three dimensional space as they become active. In terms of observation within the lab, and communication of those observations first to other members of the team and subsequently to other scientists through broader conversations and publications, the phenomena visible through the microscope – in this case highlighted by fluorescing in different colors – constitute a self-contained field of agency. This field of agency comprises agents – scientific phenomena (molecules, genes, fluorescence, etc.) – whose agency is evident through their interactions with and effects on each other.

But it would be a mistake to regard this field of scientific agency to be limited only to the phenomena under observation in the lab. The scientists themselves also participate within this field of agency as the register of the scientific phenomena under observation, through their senses, and as organizers of the phenomena through their manipulation of lab tools and technology. With this in mind it is possible to appreciate how powerful is the impetus towards technical scientific discussions between the inventor and the team members during the early stages of an i-Teams project. Fields of agency define the entities and the capacities that matter within a particular cultural context. The scientific-technical discussions about the inventors' technologies are a vehicle for expressing and reproducing the team's participation in science culture with the inventor.

We might draw a parallel with what the anthropologist Alfred Gell terms, "technologies of enchantment," in the context of the at once simple yet beguilingly complex decorative prows of the canoes used by Trobriand islanders on their Kula expeditions:

> I am impressed by works of art in the extent to which I have difficulty… in mentally encompassing their coming-into-being as objects in the world accessible to me by a technical process which, since it transcends understanding, I am forced to construe as magical. (Gell 1992: 49)

Here the aesthetic technology of the intricate Trobriand canoe prow designs imposes its agency on observers, subjecting them through its powers of enchantment. And just as the technical virtuosity of the Trobriand designs transcends understanding and thus seems like magic, to some extent the scientific technicalities being discussed between the inventor and the i-Team, whilst they remain only partially explained and understood, can also be seen as, "a technical process which… transcends understanding" and thus invested with a kind of magic, which commands attention. Indeed, given the multi-disciplinary nature of the i-Teams, with team participants drawn from a range of science disciplines both directly and more indirectly related to the inventor's technology, there will always be a range of levels of technical comprehension of the technology within the team, with some team members relying on a more approximate, gestalt understanding.

The first phase of the i-Teams project thus operates to some extent within this realm of 'enchantment' by the power of scientific agency. The aim of the i-Teams program is to break out beyond the limits of scientific agency to confront the teams with additional fields of agency with which their technology must engage in the world beyond.

*Phase Two: Loosening the Bonds*

In the second week of the project, having been briefed on the inventor's technology, the team undertakes a brainstorming exercise to generate a broad range of ideas about potential application use cases for the technology, aiming to broaden the scope as far as possible beyond the inventor's in-coming assumptions, to consider different end-users, use cases, usage contexts, product/service categories, or industry sectors. Adopting standard brainstorming rules and best-practices, the aim is to encourage the team's thinking to diverge as much as possible, and to embrace speculative leaps.

Though this form of brainstorming is common practice in many commercial work contexts, and absolutely routine in human-centered design practice, most i-Teams team members will not have been exposed to it during the course of their scientific education and careers. It represents an important first, small disruption of the norms of science-culture that the teams and inventors bring to the projects, and makes a first shift in terms of agency.

In terms of scientific agency, the propositions which inventors bring into i-Teams projects commonly make clear links between technical performance characteristics of their new scientific technology, often substantiated by academic publications and/or patent applications, and the application use-cases which they believe represent a potential commercial opportunity. Scientific agency is central to these propositions: the science has these technical features and capacities, therefore it is able to deliver these significant performance improvements when applied. The speculative nature of the brainstorming process shifts the conversation away from strong and direct links between scientific agency and resultant product or service benefits, and makes a first step towards recognizing that successful innovation and value proposition development will involve a dialogue between scientific agency and other forms of agency located in potential application contexts. To say that the technology "might" be relevant in a different application context to the one(s) initially defined by the inventor is to begin to open the team up to the fact that meaningful propositions are defined by more than scientific-technical specifications. There is also an aspect of starting to realize that finding the best value propositions may not be an obvious element that derives straightforwardly from the technical specifications, and that the process of identifying real-world applications therefore encompasses a creativity and element of exploration of its own.

It is important to note, also, that at this stage in the project the team is starting not only to make the first shifts in terms of the fields of agency which they embrace as relevant to their innovation task, but also to make shifts in terms of their experience of their own agency as scientists. The open, collaborative, inclusive nature of the brainstorming as a mode of team working represents a significant change for many of the post-graduate scientist team members from their more structured experience of scientific lab team work. Indeed, many i-Teams participants say that one of their primary motivations for wanting to join the i-Teams program is to experience a more collaborative form of team working.

In supporting these two different types of shift in agency – in terms of scientific versus other contextually embedded fields of agency, and in terms of the scientists' own agency – the i-Teams project approach works with science innovation as an embodied practice. Just as experimental lab science is an embodied experience with the scientist at the heart as register/observer, the process of translating between science culture and commercialization during an i-Teams project is an embodied, experiential process.

*Phase Three: Crossing the Threshold*

The third phase of an i-Teams project might on the surface seem the most straightforward and mundane, but in many ways it is the most critical. Having defined and prioritized a set of potential application areas to investigate, the next step for each team is to engage with potential stakeholders to explore the contextual factors in each application area which will determine the potential to deliver a successful value proposition based on the inventor's technology. The first step in this process is to set up conversations – with experts in relevant industry sectors, or with potential business or consumer customers.

Just as the brainstorming process is a new and unfamiliar experience for many i-Teams participants, the prospect of conducting conversations with unfamiliar people outside the university also presents itself as a new challenge. Recognizing this challenge, the i-Teams program includes a workshop session on conducting successful conversations, which introduces the team members to effective questioning and listening approaches and allows them to explore and manage their own conversational habits via role-play exercises. The workshop frames the conversation challenge as both a theoretical and technical one – in terms of effective question types and investigative approaches, and also as an emotional and psychological one – in terms of putting oneself in a position to conduct the interview in a relaxed, open and confident manner.

This stage in an i-Teams project is commonly the most difficult one. Teams contact large numbers of potential contacts via email and social media. There is an anxious period of waiting for responses, which frequently come more slowly and in lower numbers than the teams hope. After the more straightforward activities of the early stages of the project, this first attempted encounter with the outside world introduces a sense of jeopardy into the projects. Will sufficient people respond? Will team members be able to execute the conversations effectively? Will the right kind of people respond, and will the conversations with them provide insights that help the project progress positively?

During this part of the project it is natural for some of the teams to become discouraged if things do not go quite to plan. The team mentors and the i-Teams staff are required to provide encouragement and coaching about additional strategies for making successful contact with useful informants. However, what might seem at times like an Achilles heel of the process – the unpredictable dependency on timely response from external contacts during a time-constrained project – is actually a crucial experiential component of the process. It is at this stage of the project that teams start to have some feeling of actually being in a startup: through pressure of time ebbing away whilst unpredictable external factors impede progress; through the need to challenge oneself by taking on new and unfamiliar roles and skill-sets; and through the need to collaboratively define and assign work roles and tasks, and depend on team mates.

This phase is a liminal one, which dramatizes the process of crossing the threshold to take the science beyond the confines of the university – and as with the previous phase, for the team members, it is an embodied experience which makes a further shift in their role as researcher-creators.

*Phase Four: Encountering other Actors*

i-Teams projects involve a range of ways of engaging with stakeholders and potential users or customers, from email exchanges, to phone conversations, in context interviews and visits, and focus groups and co-creation sessions – depending on the nature of the inventor's technology, and the products or services envisaged. But it is the phone conversations which are usually the team's first experience of testing the inventor's proposition which are most significant in helping the team make the leap from thinking of the proposition in technical or scientific terms, to starting to discover other fields of agency – other actors and forms of agency. This will typically take the form of a conversation with an R&D scientist or product manager working for a company that is a potential user of the new technology – either within their own industrial processes, or within their products or services. The conversation may start with a discussion about the technical features and intended benefits of the inventor's technology, but when the conversation goes well it will then open out into a broader discussion in which the external expert starts to introduce a range of contextual factors to qualify the nature of the opportunity – from requirements, dependencies and performance and cost benchmarks within a relevant industrial process, to the competitive landscape for comparable solutions, or the needs and constraints of end-users or consumers. It is through these conversations that the teams first become acquainted with the additional fields of agency – industrial processes with their interrelated technical systems and human actors; landscapes of competitive solutions; end-users and consumption contexts - with which the scientific agency of their technology must engage.

These conversations unfold differently than if the i-Teams participants were experts in human-centered design qualitative interview techniques. Rather than the interviewer guiding the interviewee through a discussion which reveals the contextual factors, relationships, meanings, etc. that comprise the anatomy of the product or service experience, in these interviews the balance is more towards the interviewee volunteering details about the usage and/or consumption context in order to offer advice about why, or why not, and how, the technology solution that the i-Team member is introducing might work, and might be adapted or improved. Though viewed in terms of human-centered design best practices, these conversations may not seem ideal, in terms of the step-by-step experiential learning process of the i-Teams project there is a valuable logic, consistent with the embodied, experiential nature of the earlier project phases. To conduct these conversations in the style of expert human-centered design interviews would require the scientists to bring to the conversations a prior model of what they want to discover. Instead, what happens is that the i-Teams participant encounters the new fields of agency as they are revealed by the interviewee, and in most cases needs to be willing to use this information to challenge and adapt their own assumptions and preconceptions. It is an experiential process in keeping with the scientist's discovery mode in the laboratory, enabling the scientists to extend the scope of their investigation to include additional fields of agency beyond the scientific agency which dominated it at the outset.

*Phase Five: mapping fields of agency interacting over time*

The final phase of the project, focused on articulating plans and recommendations for how the inventor should proceed with commercialization of the technology, is underpinned by the concept of mapping out dependent activities over time. This is a process which begins as soon as the team starts reporting back at each of their regular meetings on the findings from their interviews and fieldwork. With each member of the team investigating a different application context for the technology – or different aspects of the favored application context – the discussions at these meetings unfold as an implicit evaluation and prioritization of different aspects of the commercialization opportunity. Inevitably, the conversation turns to questions of sequencing. Which potential application area is most primed for adoption of the value proposition? Which user or consumer group is most likely to adopt first? Which opportunities require lengthy processes of proof of concept, technology development, or regulatory approval? As conversations with expert stakeholders and end-users, and other fieldwork, continues over the final weeks of the project, the team starts to form its point of view about what its final recommendations to the inventor will be, through an iterative process of value proposition refinement and opportunity prioritization.

The shift towards thinking in terms of roadmaps and processes unfolding over time is reinforced at the start of the second half of the project by a Design Thinking workshop focused on developing a journey map for one or more of each team's potential value propositions. The simple device of considering how a product or service experience varies over time in terms of its contexts, constraints, dependencies, etc. is experienced by the teams as a powerful new way to reveal the challenges and opportunities involved in successful delivery of the value propositions they are considering. This marks another important shift away from the scientific model of agency which dominates at the start of the project. Whereas within the scientific model, processes under consideration are necessarily specific and strictly defined and controlled in order to isolate the characteristics and effects of scientific phenomena (a defined field of agents and agency), journey mapping introduces the teams to a mode of working which aims to be as open as possible to discovering any and all possible contextual factors which might influence the successful delivery of a value proposition unfolding as a process over time. This openness embraces the discovery of new potential agents and agency within the experience (e.g. additional user or consumer stakeholders; other technologies, services or processes on which delivery of the value proposition is dependent; etc.) as the route to successfully realizing the opportunity to deliver impact through the inventor's technology.

Projects conclude with the teams presenting commercialization plans and recommendations for their inventor's technologies to an audience drawn from Cambridge's science and technology commercialization community. These recommendations usually take the form of prioritized application areas with revised and refined value propositions and associated business models. It is common for more than one application area to remain in consideration, and for the different options to be represented in the form of a roadmap which articulates how the delivery and business models for each value proposition will combine over time to deliver a sustainable route to realizing the full potential impact of the technology. It is common for projects to result in ongoing conversations with potential customers, partners or investors which will provide initial impetus for the inventors to embark upon the roadmap identified by the team. (Not all projects are able to identify potential commercialization roadmaps: in these cases the team may be able to specify additional technical development and proofs of concept that are required first.)

Presentation of commercialization roadmaps is a dramatic enactment of the journey that the teams have made from the start of the project, focused on the technical details of a new scientific technology, to the point at which the technology has taken its place in a story alongside many other actors and fields of agency. The commercialization roadmap, as with the journey maps that the teams create, is a powerful tool for enabling the scientists to take account of and navigate between the multiple contexts, and multiple fields of expertise. Within it they represent input from diverse perspectives, which might include scientists, technologists, industrial process engineers, users, customers, patients, marketers, intellectual property experts and investors. The roadmap provides a vehicle for holding together what might seem incommensurable perspectives, just as the overall process of the i-Teams project itself provides both team members and inventors with an embodied experience of how they might be able to inhabit not just the role of scientist, but also the other broad range of roles required to embark upon the commercialization of science through startups.

The experiential nature of the i-Teams project process does not seek merely to bolt on new disciplinary perspectives and skill sets to its scientist participants, overlaying them with human-centered design, entrepreneurship and business management skills. It is designed, rather, to give them hands-on experiences and increase their skills and awareness of the complexity of the commercialization process by doing so. It builds on their existing expertise and creativity, making as much use as possible of the skills they already have to give them confidence in their own ability to adapt to new contexts outside of academic research. It aims to nurture the agency of the scientist as researcher and creator, and allows them to expand the scope of their ambitions, and of their areas of interest. It exposes them to new ideas in a way that allows them to realize that commercial questions can be just as engaging as (or even more engaging than) scientific ones.

## OPPORTUNITIES TO SUPPORT PRE-STARTUP SCIENCE COMMERCIALIZATION

Earlier in the paper we posed the following question: In what ways might science innovation not conform to the expectations of human-centered design practitioners coming from the world of commercial innovation? We can broadly characterize the differences thus:

**Table 1. Differences Between Science Innovation and Commercial Innovation**

| | **Science Innovation** | **Commercial Innovation** |
|---|---|---|
| **Process** | complex, obscured, accidental<br>science technology IP-centered | rationalized, iterative-phase-based<br>human-centered |
| **Collaboration** | informal, opportunistic, local<br>individual-based | organized, aligned, integrated<br>functional team-based |
| **Culture** | value generation depends on and reinforces science culture | organizational and disciplinary cultures recognized, but managed, and subordinated to objectives |
| **Objective** | impactful scientific knowledge | brand / lifetime customer value |
| **Primary Delivery Vehicle** | scientist | value proposition |

It might be tempting to read the differences outlined above as evidence that science innovation is at a similar stage of development along a pathway towards human-centricity as technology product companies were thirty years ago. But this would be to mistake the fact that science innovation is, necessarily, driven by different imperatives, towards different ends. Whilst university science is increasingly becoming the de facto front end of emerging Innovation 4.0 innovation processes, it cannot become fully submitted to that role.

The 'impact' imperative which shapes much of the scientific research agenda through the funding process is a nuanced concept with some ambivalence at its heart. Under this imperative scientific work must be linked to impact, but not fully committed to delivering impact. The positive impact of scientific knowledge in the world remains a secondary effect of delivering impactful scientific knowledge.

In the concluding sections of the paper we will reflect this dualism by considering, firstly, how ethnography and human-centered design can support science innovation in becoming more human-centered and more integrated and aligned with commercial innovation processes, and secondly, how ethnography and human-centered design can support scientists in their own pursuit of impact.

## Supporting University Science Innovation

Table 2 maps the science innovation journey described in this paper against the main elements of university technology commercialization ecosystems through which ethnographers and human-centered design practitioners might be able to engage, and indicates where human-centered design capability is currently most likely to be found.

**Table 2. University Science Innovation Journey**

| | Basic Science Discovery | Application Context Identification | Impact Potential Identification | Application Validation | Value Proposition Development | Business Model Development |
|---|---|---|---|---|---|---|
| Science Depts. | | | | | | |
| Innovation/ Design/ Business Schools | | | | X | X | X |
| Humanities & Social Science Depts. | | | | | | |
| Student Societies | | | | | X | X |
| Policy/Issue Centers & Institutes | | | X | X | X | |
| Technology Transfer Office | | | | X | X | X |
| Investors (Angels, VCs, Corporates) | | | | | X | X |
| Incubators, Accelerators | | | | | X | X |
| Startups | | | | | X | X |

X = *areas where (often limited) human-centered design support for the process currently exists*

It can be noted from Table 2 that human-centered design support is so far present mainly in the later stages of the science innovation process. This is where existing support for pre-startup commercialization tends to become engaged, usually at the point at which the concept for a potentially commercializable technology application has already been developed, which inevitably limits ability to maximize the human-centered potential of the original scientific idea. The opportunity remains, therefore, to engage with the earlier stages of the science innovation process outlined in this paper to support a richer alignment between emerging science-driven technologies and meaningful problems in the world.

There are two main dimensions to this challenge: the structural and cultural complexity of university science education; and the availability of viable business models for delivering human-centered design support at this stage of the process.

Existing vehicles for intervening within the complex ecosystem of science innovation may provide useful models. Notable amongst these is Stanford's D-School, which since 2005 has made human-centered design accessible as a core practice competency across the university, and which in addition to facilitating science's engagement with meaningful problems, has also explored the potential of introducing Design Thinking principles to the science discovery process itself (Yajima 2015). University initiatives advancing the agendas of development and sustainability also provide successful models for engaging with the basic science research agenda. Examples include the Stanford Center for Social Innovation (www.gsb.stanford.edu/faculty-research/centers-initiatives/csi), and the Centre for Global Equality's Cambridge Inclusive Innovation Hub, hosted in the University of Cambridge by the Department of Chemical Engineering and Biotechnology (www.centreforglobalequality.org/inclusiveinnovation/cambridgeiifhub). Initiatives such as these have used the UN Sustainable Development Goals as a persuasive vehicle for mobilizing academic research efforts. Ethnography and Human-centered design practitioners might look to learn from and build on this success to promote engagement with a broader scope of meaningful human problems beyond the development and sustainability agendas.

Developing business models for this work is the other challenge. In her 2016 EPIC paper, Julia Haines proposed that the role of Ethnographer in Residence might be adopted by venture capital funds, on the model of the Entrepreneur in Residence role, to support more meaningful and thus more commercially successful innovation. (Haines 2016: 196) Adoption of ethnography and human-centered design in the startup sector may prove a useful bridgehead and case study to promote adoption further upstream in the process – but there is no doubt that this represents a significant innovation and business model design challenge in itself.

We therefore propose the following agenda to advance the cause of ethnography and human-centered design support for science innovation:

1. Ethnographic research to map science innovation journeys through the complex organizational structures and cultures of this ecosystem
2. Human-centered design work to translate that understanding into journey maps as a resource for mobilizing collaboration and designing support solutions
3. Collaboration with stakeholders in science innovation ecosystems to innovate business models for the inclusion of human-centered design activities

## Supporting Scientist Innovators

Our ethnographic vantage point for this paper has been from the perspective of a pre-startup science commercialization program in Cambridge University, i-Teams, and the experience of the scientists that the program supports. And so our focus has been on the journeys that those individual scientists make from their first interest in learning about science, through scientific research, to discovery of potential for impact in the world, and on to beginning the process of making that impact a reality through the i-Teams pre-startup commercialization program. In terms of the differences between science innovation and commercial innovation outlined in Table 1, we can see that viewing science innovation from the perspective of the individual journeys of scientists is quite appropriate. For one of the fundamental differences between science innovation and commercial innovation is that whilst commercial innovation is organized so that the solutions that it creates are seen as the product of abstract functional entities (teams, departments, divisions, brands) rather than individuals – with market value propositions being the entity which is focused on and moved through the process – in science innovation, the generative agency which brings forth new ideas and solutions, and the ownership which confers responsibility to take those ideas forward, is located in specific individual scientists – with scientists themselves being the entity that the system focuses on and moves through the process.

In this final section of the paper we consider the potential for collaboration between ethnographers and human-centered design practitioners, and scientist innovators. In one fundamental respect this might be different to the collaborations forged with technical disciplines and functions within corporations over the past thirty years or more of commercial human-centered design. For unlike engineers, scientists are, in the first instance, researchers seeking to understand how the world works. And in this respect they have a fundamental affinity with social science driven human-centered design, which also seeks first to understand, then to change.

In the course of our research with the scientists who had participated in the i-Teams program, it was striking how many of them located the moment that their vocation in science crystallized in an early experience of observing scientific phenomena under the microscope in a lab. They used the image represented by this experience to articulate the drive they feel to understand how the world works. In practice, how the world works is usually addressed at the level of specific scientific phenomena which become observable, or are made theoretically evident, within the lab – translating into a quest to understand how 'things' work. Table 3 draws on our research and the scientist innovator journey outlined in the paper to sketch out a re-framing of the science innovation journey represented in Table 2 (which shows the process at the level of the university and its associated science commercialization ecosystem) to show it from the perspective of what engages and motivates the individual scientist innovator.

**Table 3. Outline for Journey Map of the Scientist's Innovation Journey**

| | How Do Things Work? | What Can They Do? | Where Can That Make a Difference? | How Can I Make That Happen? |
|---|---|---|---|---|
| 'Cool Science' Imagination | | | | |
| Lab-Tech Artisanal Skills | | | | |
| Embodied Observer/Instrument | | | | |
| Science Knowledge Community | | | | |

The four phase process outlined in Table 3 lays out in simple form the logic which leads scientist innovators from fascination with how things work; to curiosity about what the scientific entities that they have observed or discovered can do in the world; to engagement with where and how that could have positive impact; and finally to embarking upon making that impact a reality. We have mapped these phases against four key dimensions of scientists' dispositions and skills to form the provisional outline of a journey map. It is the fleshing out of this outline journey map through further ethnographic research, and the development of solutions to support the journey of scientists, that we believe represents the most important opportunity for ethnography and human-centered design to engage with science innovation.

Why would we believe that focusing on the scientists, as opposed to focusing on embedding meaningful human problems in the science innovation process itself, is the more important opportunity to support human-centricity in science innovation? This is because we see the current science startup phenomenon as ushering in new possibilities for managing the impact that science-driven innovation has in the world by enabling scientists to remain directly involved in the commercial development and implementation of their solutions. The nature of the scientific platform technologies emerging in the fields of genetics, nano-materials, plant biology, etc. means that the relatively small, focused resources of startup companies – as opposed to large corporations – can be sufficient to bring the technologies to market. The startup company model pioneered by the first genetics-driven biotech startups of the 70's and 80's – science and scientist-led, with strong continuing links back in to academic science, and basing valuation on science IP creation as well as financials (Powell and Sandholtz 2012: 401) – is increasingly viable and available to scientist innovators and entrepreneurs across a range of science disciplines.

What this makes possible is the prospect of different conditions for managing the impact of the agency of scientific technologies in the world. In the mid-twentieth century science innovation model, in which new scientific technology was handed over the wall from university science labs to industry, we might not be surprised if the internal systemic logic – the scientific agency – which is baked into new technologies, once out of the hands of those who created it, results in unintended consequences when deployed in contexts where recognizing and supporting human agency is paramount. The current science-led startup company model offers at least the prospect of a different situation, in which scientists follow the journey of their technology – as in the example of the i-Teams project process outlined in this paper – from its origins as a closed system of scientific agency, through encounters and constructive engagement with other fields of agency as it moves through the commercialization process.

The opportunity that we present in this paper is, therefore, for ethnography and human-centered design practitioners to engage with the human-centered design challenge of supporting the agency of scientist innovators on their journeys from cool science to changing the world, and enhancing their ability to transform the scientific agency embedded in their technologies into solutions which enhance human agency.

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1. The Cambridge i-Teams approach was derived from MIT i-Teams in 2005-6 with the support of MIT.

2. Development i-Teams is a more condensed program, consisting of 6 sessions over 5 weeks. Development i-Teams was developed in partnership with Dr Lara Allen of the Centre for Global Equality in Cambridge, UK. Medical i-Teams was developed in partnership with the Cambridge Academy of Therapeutic Sciences.

3. Whilst the majority of i-Teams participants are drawn from the science disciplines, there is some involvement from social scientists, particularly on projects relating to health or development.

4. This also allows the participants to start the projects in a way that is strongly within their comfort zone and the scientific culture that they know and understand, before they start to be challenged to move outside that into the commercial world during the program. Often they are already being challenged in this first meeting by working with scientists from very different scientific disciplines who they would not normally have the opportunity to meet.

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