Knowledge Sharing - Cultivating a creative commons

Steve Hughes, Co-Director ESRC Centre for Genomics in Society, Exeter University, Exeter, UK
s.g.hughes@ex.ac.uk

With respect to my title I have to point out that there is a liberalised-licencing institution known as the Creative Commons (proper noun) whereas I use the term (common noun) to portray a space of creative activity and problem solving, based on the sharing of knowledge, both heuristic and instrumental, by diverse actors.
As an entrée to the subject of knowledge sharing let me also state that I shall try to avoid getting drawn into the social discourse on knowledge production especially that which requires that knowledge in order to be recognised as such has to be negotiated and installed in the broad social context. In this context knowledge exists through sharing and knowledge-sharing is non-problematic, it is a given. At the same time I do cling to the "socially-installed" criterion as a qualification of the term ***innovation*** be that in consumer products, professional practices, or styles of thought . It is to innovation and to instrumental knowledge that I will turn my attention.

When I first entered science some 55 years ago (as my father's Saturday assistant, aged 5), my stamp collection (postage stamp collection was a popular pastime in those days rather than a solitary pursuit of the investment-conscious or the terminal anorak) was the envy of my fellows. I had the stamps of countries I scarcely knew and had to search for in the atlas, thanks to a phenomenon which some of you will certainly recognise, the reprint request. My father was a publishing scientist who invented a scientific instrument, accounts of which became a citation classic. Needless to say, as the invention became part of common practice in microbiology, he received an enormous set of requests for reprints of his publications. In return for my stamps I helped to dispatch the reprints which slowly airmailed their way around the planet and supported the construction of many facsimiles of the instrument (some of which were improvements on the original). We also sent out requests for reprints from other scientists. Of course, I did not appreciate at the time the role I was playing in the innovation process, but perhaps I can be forgiven for taking on the naïve assumption that knowledge-sharing was an uncontested norm for scientists in their craft. Shoulders, all shoulders, were there to be climbed upon. You can climb on mine and one day perhaps I can climb on yours, was a logical extension of childhood games.

Somewhat later, when I made my own professional entry to science I was due a shock. Several days into my new job as a research assistant at the University of Edinburgh in September 1967, I observed the Professor's technician making parcels of a journal from the library shelves. The journal in question was the very prestigious PNAS, The Proceedings of the National Academy of Sciences of the USA (again many of you will recognise that these days the content of this journal is available on line to anyone with an internet connection). "Why are you doing that I innocently asked?". " I am preparing to send some recent volumes of the journal to Cuba. The embargo imposed on Castro's post revolutionary Cuba by the USA prevents them from receiving scientific journals, so Martin donates them his personal copy." Perhaps this was an unlikely and slightly early moment to lose my intellectual virginity or naivety, but to discover that US political power was being used to restrict the sharing of knowledge in such a blatant way was a disappointment, and a formative one, especially when I remembered the number of American stamps in my young collection. It was a rude awakening indeed to the concept that "other" groups, be they ideological, commercial rivals or just distant nuisances in a late-developing world, may be regarded as legitimate targets for ignorance. Knowledge and power beyond being metaphors of each other (Francis Bacon) became mutually manipulative bedfellows but I lacked the vision and courage to separate them. Or was I just confused by the assumption that science and knowledge production was, still then, a production rather than a consumption -oriented economy? Regardless of the confusion, my own career has been very much aligned with the instrumentality of knowledge and the gearing of discovery into innovation, and has been closely engaged with the consumption-oriented paradigm of the late twentieth century.

From my recollection a significant shift in practice and in scientists' expectations came on the heels of the diffusion of recombinant DNA technologies and the success of the licencing strategy of the corresponding Cohen-Boyer patent[1]. Until that point there was a culture of sharing represented for me by the small Dewar flask containing tubes of restriction nucleases or other key enzymes or other reagents, in ice, which accompanied all of us on our travels to be shared with other inestigators. Of course Cohen-Boyer was not the first biologically based patent which supported a notable innovation or generated institutional income. One can quote the discovery and re-synthesis of Cephalosporin antibiotics and the pyrethroid insecticides both of which translated into significant institutional income.
Collectively these successes imposed an new opportunism on science practice witnessed by the subsequent flush of biotechnology start-up company of the 1970s and 80s. They are stories worth reflecting upon:

Cephalosporins

Despite the combined efforts of Oxford, Clevedon and the Glaxo Group there proved to be many difficulties with the production of Cephalosporin C and it took until 1959 for Abraham and Newton to determine its chemical structure. Later that year they showed that subtle mutations of the Cephalosporin C molecule could lead to the production of more potent antibiotics which would still be resistant to penicillinase. Work aimed at producing higher yields of the nucleus of the molecule continued during the early 1960s, with Glaxo, Eli Lilly, Merck and other pharmaceutical laboratories licensed by the National Research Development Corporation (NRDC) collaborating with the Dunn School. The successful outcome of this painstaking work enabled studies of semi-synthetic cephalosporins to proceed, with the drugs cephalothin and cephaloridine being introduced into medicine in 1964. The NRDC's worldwide patenting and licensing scheme covering the cephalosporins eventually yielded huge royalties, for many years the chief source of income for the corporation. Abraham diverted the greater part of his royalty income into two trusts, the E.P. Abraham Research Fund and the E.P.A. Cephalosporin Fund, which he set up to support medical, biological and chemical research, especially at Oxford. [2]

Pyrethroids

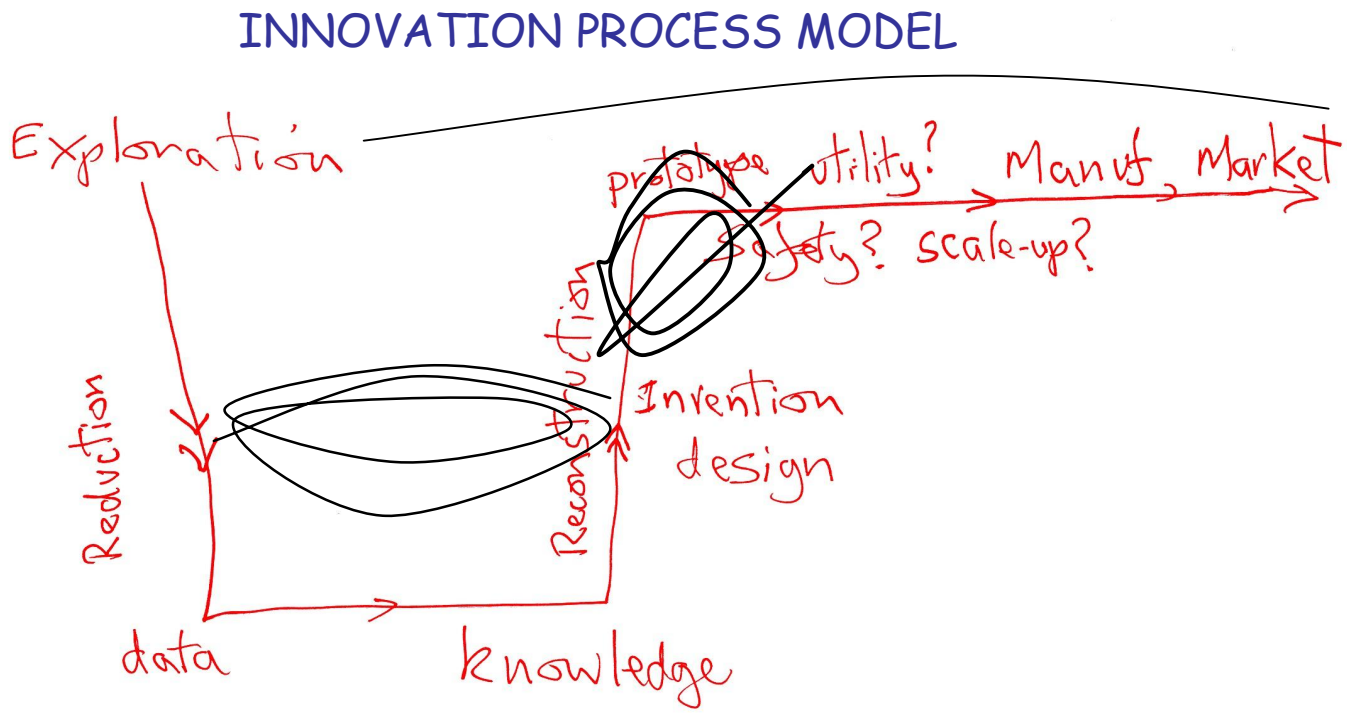
NRDC (National Research and Development Corporation, a British government corporation) in England owned the rights to Michael Elliott's patented chemicals (since Elliott was a scientist employed by the British Government at Rothamsted Experimental Station). NRDC developed the pyrethroid market through a number of licensing agreements. They sold the United States rights to market and sell permethrin to FMC who sold it under the Trade name ***Pounce*** *and ICI, Americas (now called Zeneca) who marketed it as* ***Ambush****. Later a cypermethrin license was sold to FMC who marketed it as* ***Ammo****, and also to Zeneca who marketed it as* ***Cymbush****, and these products were highly touted as new and improved.* [3]

These examples of spectacular innovation stemming from exploratory research in the biosciences help to set a scene for patenting of biological invention and presaged an explosion of biopatenting in the 70's. Academic institutions all now have their technology transfer departments and innovation officers all of them hoping for success like that of recombinant DNA (rDNA), cephalosporins and pyrethroids and all determined to avoid missing opportunities like that of the much regretted monoclonal antibodies. Intellectual property policy is now a platform for research activities and provides new expectations in the reward system for scientists. Instrumental knowledge is at a premium and governments call out loud for innovation and competitiveness as an outcome of their investment in science research and education.

Innovation

[1] the Cohen-Boyer patent generated significant financial income for the University of California through broad licensing to biotechnology companies.
[2] NCUACS guide to the manuscripts of British Scientists , entry for Sir Ted Abraham
[3] http://wcb.ucr.edu/wcb/schools/CNAS/entm/tmiller/1/modules/page28.html

This discussion is based on a particular model of innovation based on my own experience and relevant to some of the applications of biotechnology, which I first started to elaborate in 1990 (Hughes Colombo and Valanzuolo 1990) and which I have pedalled furiously and serially modified since (Hughes 1996, Hughes and Batty 1995). Central to the model is recognition that innovation is a multi-actor process resulting in *an innovation*, that being something which is new and significant, and installed in markets or in working practice. In other words innovation implies social penetrance[4]. As this implies in turn, there are many ways in which innovation can fail to produce an innovation. Consider herbicide tolerant crops produced by transgenic technologies (shorthand = GM). While in the USA these are clearly an innovation in agricultural practice and in the food consumer market, in Europe they have not penetrated agricultural practice and are resisted (excluded from food formulations) by food manufacturers. The innovation model can be configured as a linearly coupled set of actions performed by discrete actors with breakdown at any step implying failure.
Figure1.



In this light it is interesting to examine why and at what step herbicide tolerant crops failed to become an innovation in European agriculture, and this we will do later.

While accepting the sequential nature of much of the process and admitting that there is an underlying order of precedence of the transactions within it, I suggest that it is conditioned by both iterative (feed-back, feed-forward) and negotiative exchange between distant as well as adjacent actors. As such it may be represented in a pictogram as a set of linked vectors decorated with iterative spirals and feed-back loops (figure1.) which in the extreme can become impenetrable and difficult to navigate (Hughes 1996). At the same time the model needs to conserve flexibility in order to represent the possibilities of diverse settings and actor sets. The diversity of settings may be characterised and illustrated by extremes. One the one side we might examine an institutional or corporate setting in which the process is managed and coordinated via a set of codified and hierarchical instruments linking the actors, the supply chain, the novelty and the externalities of regulation and the market. Such a highly coordinated setting might be expected to minimise transaction costs and the friction between actors as well as providing defined and timely decision points at which likely failures can be abandoned. At the same time they provide an environment for overall corporate innovation strategies designed to rationalise and spread risk exposure, but these can lead to the abandonment of potentially successful projects solely on the basis of risk aversion or a poor fit with corporate strategy or culture. Thus innovation chains organise as much as

[4] I use the term penetrance with its genetic connotations of dominance coupled to variable and spasmodic impact as a more appropriate and colourful illustrator than the word penetration.

decision making tools as they do logistical activity networks. At the other extreme we can envisage an isolated inventor requiring the construction of a de novo set of actors from the diverse specialisations as well as the procurement of external capital in order to start the innovation process. This scenario is illustrated by the now classic biotechnology start-up company founded on venture capital. The challenge for such ventures is to achieve an adequate penetrance before the investors lose confidence. The difficulty for the small venture of dealing with externalities and of managing a set of disparate actors and transactions commonly leads to failure or acquisition by a larger company (example Monsanto's acquisition of Calgene)

Another range of settings may be characterised by the nature of the receiving environment. On one side of the extreme we may observe saturated markets or established practice where there is intense competition for penetrance in which novelty is used as a lever. On the other we may observe environments where there are deficits for which novel solutions might lead to a welcome innovation. The former category is characterised again by the large corporate venture and in some cases by the biotech start-up company (eg Calgene and the FlavSavr tomato). This setting aligns to a degree with the oft quoted "Technology push" style of innovation. The latter setting has more to do with the interplay of adoption and opportunism and is driven as much by need (market pull) as technology.

I would argue that the model I articulate does provide for these diverse settings and can help to identify the key interactions and bottlenecks to knowledge-sharing. I will illustrate the utility of the model in this regard by examining two areas of activity characterised by groups of actors, those involved in the production of the novelty component and those in the user community.

Origins of the novelty component

The source of novelty is frequently associated with the acquisition of new knowledge and I would argue that it is ultimately dependent upon the continuing production of knowledge. A familiar representative here is the discovery of new DNA sequences related to disease proneness in the "invention " of new diagnostic tests for use in public health screening. Where the generation of novelty is closely linked to the acquisition of new knowledge there is a strong imperative to protect that knowledge by patenting. This restricts the possibilities for the accessing of instrumental knowledge which is to say that it places the possibility of new knowledge becoming instrumental beyond access for all save the initial investigator.

Much new knowledge is produced in the course of what I term exploratory research. This may be viewed as the process of visiting and exposing features and relationships in the natural world which were hitherto hidden from us.

Acquisition of observations or data, which can be stacked according to the mode of its acquisition, to test hypotheses and to build theory and explanations of causality, is the first step of the process. The subsequent building of theory is equitable with mapping as a means of stabilising and representing emergent knowledge and reporting back on the newly explored territory. The mapping metaphore is valuable in relation to the ensuing navigation of the territory by others in the testing of theory and in pushing exploration further. This emphasises the dependence of discovery and knowledge production on what has gone before and what is verified by others. As I iterated earlier we stand on each others shoulders, rarely are we uplifted by a giant. This frames knowledge production as a networked activity in which the precise provenance is difficult to attribute.

A remarkable example in this regard lies in the large scale international investigation of the relationship between the bacterium *Agrobacterium tumefaciens* and its plant host. This organism has been broadly recognised and hailed as a "natural genetic engineer" thanks to its remarkable and supposedly unique ability to mediate the transfer of part of its own DNA complement into plant cells. Thousands of man-hours of research effort by hundreds of workers, much of it funded from the public purse, went into understanding the mechanisms by which DNA transfer is achieved and into suborning this mechanism to the transfer of DNA segments chosen by plant geneticists. Latterly, timely research interventions building on this knowledge by well resourced companies in the bio-industry community produced a robust gene transfer technology based on *Agrobacterium* and enabled these companies to control that technology as formalised intellectual property through a suite of patents (see www. BIOS.net white papers). Consolidation within the ag-bio industry means that this technology is effectively controlled by

two major transnational corporations who are able to selectively exclude others from practice of the technology and from this avenue of innovation.
As the above example illustrates, it is in the creative bringing together of knowledge thus acquired in diverse fields to produce a new enablement that individually attributable transformations of knowledge, inventions, are made. This process corresponds to the upward, reconstructive limb of the above diagram. As we saw, inventions may be provenance-preserved by patenting , a mechanism which rewards the inventor by assigning monopoly rights over the exploitation of the reconstructed knowledge and it is argued that this is a stimulant to further inventiveness. Sadly , as observed in the Nuffield Council on Bioethics' review of patenting of genes, latterly in practice there has been a tendency for the inventive component of patents to be degraded and for patents to shift towards being a means for annexing and attributing knowledge per se in the quest for monopoly. Nevertheless, an extensive bioindustry has grown on the back of the patent paradigm and as discussed in examples above some invention has been successfully transformed into social utility.
On the other hand, a massive portfolio of patents in the field of GM plants, many of them held by well resourced trans-national companies, much of it grounded in the pool of scientific knowledge from 20 or more years ago has not formed the basis for widespread innovation in agriculture. Only a very limited utility has yet been generated as discussed above. One explanation for this is trivial and is just a reflection of the narrow ownership of the patent field which has excluded alternative innovators. Another explanation relates in my opinion to the failure of knowledge sharing between those controlling the instrumental knowledge. We can examine this proposition by revisiting the case of herbicide tolerant plants and their failure to become an innovation in Europe.
While the causal relationships between DNA sequences and the manifestation of herbicide tolerance in plants was satisfactorily worked out by the inventors and patent holders of this technology prior to its deployment, the relationships between test-plants field-crops and agronomic practice and environmental outcomes were not. At least if they were the information did not enter agronomics-informed discourse in the UK. I do not recall any discussion for instance of how herbicide tolerance should be deployed within crop rotations or of how engineered tolerance might be deployed logistically to reduce the impact of herbicide use until SCIMAC [5]was set up in 1998 in the wake of NGO-inspired consumer reaction. Regardless of what we see when we look over the hedge, even at the extremes of monoculture, crops in the field represent a complex genomic space characterised by contributions from a large number of species including root associated fungi and bacteria, nematodes, weeds, insects, birds and mammals. These all play a role in agricultural productivity in the negative, positive long- or short-term senses. Despite recent attempts to re-engage and draw these considerations into the debate (UK Farm Scale Evaluations) the deployment of herbicide tolerant crops is stalled, supporting my contention that what's good for patenting and its interpretation of utility is not necessarily good for innovation and established utility.

The principle of exclusion articulated above, expressed in the dominant IP practices of the commercial landscape as artificially elevated technology entry price, when combined with the shear complexity of the fragmented and impenetrable patent field of genomic knowledge, can and does impede innovation. The term anti-commons was coined by Heller and Eisenberg (ref) to illustrate this form of impediment which like its more widely recognised partner the Tragedy of the Commons is particularly poignant for resource-poor communities and the potential for decentralised partnerships in innovation. The sharing of knowledge of technological enablement and of local scenarios for deployment is vital to the latter endeavours and a number of initiatives have been put forward to reverse the deficit. These consist either of proposed special derogations to the exclusionary principle (illustrated by the study case of golden rice ISAAA), technology bundling or brokering( )bennet, or else patent informatics provisions which at least explain to the resource-poor why decentralised deployment is not an option (cambia .org.)

[5] SCIMAC Supply Chain Initiative for Modified Agricultural Crops see: http://www.agindustries.org.uk/scimac/default.html

I favour what I see as a more promising approach which may reside in verisimilitudes of the peer production collaborative working modalities which have emerged from the open source software movement (Benkler 2002). An initiative intended to take us in this direction is exemplified by BIOS (www.bios.net) This initiative faces up to the key challenge of importing the knowledge management practices of the software development and implementation into the far more complex realm of the biosciences. It does so by providing not only an exhortative philosophy of knowledge-sharing but also a set of practical tools and a suite of accessible technologies under the banner of BIOFORGE to promote collaborative working and innovation freed from the disincentives of the anticommons . It also provides a platform for the open negotiation of goals for innovation so important to achieving social utility. The challenge is a stern one not only mechanistically but also in the need to persuade the diverse set of actors in the biosciences and bioindustries of the benefits to innovation of moving on from the currently entrenched assumptions about patents and market economies.
If the bios initiative meets this challenge it may manage to draw inventors from the clutches of futile technology transfer departments and back into a more satisfying and creative space of peer production networks or the commons. In such a realm they will be able to participate more extensively in the innovation chain and the transformation of knowledge through an open system of knowledge-sharing.
The Bios initiative may also convince commercial bioscience practitioners that, for them just as for the software producers, there is more to be gained through open and distributed deployment than through the traditional practices of competitor exclusion particularly when innovation depends more on fitting technology to consumer needs and practice than on force fixing markets to high technology products.

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