Institution:	University of Nottingham
Unit of Assessment:	5 - School of Life Sciences

a. Context

Research programmes in the School of Life Sciences (SoLS) have led to major impacts across a diverse range of scientific areas. The beneficiaries include multiple companies from different business sectors, such as the major pharmaceutical companies: GlaxoSmithKline (GSK) and AstraZeneca, and the consumer giants Mars and Coca Cola, their employees and shareholders, governmental bodies in the UK and overseas, families across the world with inherited disorders, athletes of all kinds, school children and the greater public at home and abroad. The geographic range of our impacts is substantial; including six of the seven continents and even outer-space. Some of the examples highlighted in case studies include impacts on:

- Commerce – 'Fluorescent Ligand Technology', 'Drug Target Validation', 'Biased Signalling for Drug Discovery', 'Industrial Process Enhancement', ' Bioengineering of Clostridia', 'Early Cancer Detection', 'Sports Nutritional Supplement Development'
- The Environment – 'Conservation Biology'
- Health and Quality of Life – 'Human Genetic Disorders', 'Sports Nutritional Supplement Development', 'Bioengineering of Clostridia', 'Early Cancer Detection' and 'Reducing Healthcare Acquired Infections'
- Social and Cultural – 'Reducing Healthcare Acquired Infections'
- International Agencies – 'Conservation Biology'

Research in SoLS is organised around ten groups and although much of this research is 'blue skies', our case studies reflect impact across a wide range of activity and are drawn from seven of the ten groups.

Six of the case studies describe aspects of commercial and economic benefit. For example, from the Molecular Bacteriology and Mycology group, David Archer's studies on filamentous fungi provided substantial value to beverage production programmes at GSK, and Nigel Minton's 'Bioengineering of Clostridia' study led to the development of unique molecular genetic tools to study *C.difficile* and other species of clostridial bacteria that have been licensed to five different companies. Members of the Pharmacology group have also generated significant commercial benefit. CellAura Technologies, the spin out company founded by Steve Hill and colleagues, provides fluorescent ligands to companies such as Abcam and Sigma-Aldrich, and work on GPCR 'Biased Signalling' by Jill Baker has generated a new market for reagents to facilitate novel approaches to drug screening for companies including DiscoveRx and Perkin-Elmer. Work by Paul Greenhaff, from the Metabolic and Molecular Physiology group, on the role of creatine in the physiology of muscle fatigue has been commercially exploited by MuscleTech Inc. to underpin CellTech, a highly successful sports nutritional supplement. More recently, the spin out company, NutraMet Ltd, was formed by the same researcher to commercialise IP surrounding augmenting muscle L-carnitine accumulation. Within the Neuroscience group, research from Kevin Fone on the role of 5-HT_6 receptors in cognitive impairment has been commercially significant, featuring extensively in patents from major pharmaceutical companies such as GSK and Hoffman-La Roche.

Additional non-commercial health-related benefits have been generated by the Human Genetics research group in which David Brook identified the genes responsible for three different inherited disorders: myotonic dystrophy, Holt-Oram syndrome and campomelic dysplasia, and developed assays for genetic testing and prenatal diagnoses that have been applied throughout the world to benefit affected families. Further examples of health-related impacts come from the Molecular Bacteriology and Mycology group, where Richard James and others in the 'Reducing Healthcare Acquired Infections' study improved public attitude, awareness and understanding of issues related to healthcare associated infections by the superbugs *C.difficile* and MRSA.

Major conservation programmes, which benefit world-wide genetic diversity and the environment, are the direct consequence of work by researchers in the Evolution and Ecology group. Building on previous conservation research from Bryan Clarke involving the reintroduction of several species of partulid land snails to Pacific islands where they had become extinct, research by Francis Gilbert has been crucial to the survival of the world's smallest butterfly, the Sinai Baton Blue. This butterfly received Critically Endangered status from the International Union for Conservation of Nature and

became the focus of biodiversity awareness campaigns in Egypt and appeared on an Egyptian stamp. These projects continue to provide an educational platform across three continents for conservation-based projects. Research from other members of the Evolution and Ecology group is also providing educational benefit in schools. For example, although not included in a case study, Peter Crittenden's work on lichens as indicators of environmental pollution has also been applied to learning enrichment programmes.

Other impacts not included in case studies, but ranging literally from Mars (the company) to Mars (the planet), are generated by members of SoLS acting in advisory roles. Ian Macdonald applies his nutritional research expertise to inform advisory boards for government and the major global food companies Mars and Coca Cola, whereas Nathaniel Szewczyk advises the UK and European Space Agencies on the biological effects of space exploration and investment into the UK space industry. Ian Mellor advises food and agricultural policy bodies in the United States, while other researchers contribute to public policy bodies in the UK. For example, David Turner for the National Institute for Health and Clinical Excellence (NICE) and Will Irving for NICE and as the Chair of the Department of Health Expert Advisory Group on Hepatitis. Thus, research from members of SoLS impacts a multitude of beneficiaries in a broad range of areas.

b. Approach to impact

The most important element running through our case studies and responsible for the impact of our research, is the persistence and tenacity of outstanding scientists. To achieve this impact we have adopted four main approaches:

1) Academic Presentation – conference seminar or journal publication of research findings, leading to recognition and contact by non-academic beneficiaries with subsequent exploitation.
2) Proactive Marketing – deliberate targeting of potential non-academic partner(s) or beneficiaries, leading to their engagement to generate the impact.
3) Planned Exploitation – research undertaken with the intended purpose of exploitation or commercialisation, by formation of a spin-out company, a partnership, or a licensing deal.
4) Partner-Directed – research and development funded by a non-academic partner, with the purpose of generating know-how and/or IP to be exploited by the partner.

For most of our case studies various combinations of these approaches have been used; an example of this multi-pronged approach is the 'Industrial Process Improvements' study. Original research by David Archer showed how fungal spores gain access to food production plants and provided a new method to improve anti-mould treatment. In the first phase of impact development, research was presented at conferences and in scientific papers. This was followed up by extensive 'cold-calling' to establish links with GSK and other potential industrial partners. This generated two Defra/BBSRC Link proposals, a Knowledge Transfer Partnership and a BBSRC Industry Partnering Award that ultimately led to significant changes in manufacturing practice at GSK worldwide. Thus, the impact was achieved by employing the full set of approaches from Academic Presentation and Proactive Marketing to Planned Exploitation and Partner-Directed research.

Academic Presentation is rarely used alone to generate Impact. However, in the 'Biased Signalling' study, the underpinning research fundamentally changed accepted understanding of GPCR pharmacology. Presentation at conferences and in journals was the primary key to impact, leading to engagement by the pharmaceutical industry because it enabled previously inconceivable drug development opportunities and subsidiary exploitation by allied reagent and service providers. Across the unit, substantial sums have been invested for conference attendance, with more than £3.3m spent over the past six years. We also promote postdoctoral and PhD student attendance at conferences, with each student receiving at least £1k to attend an international meeting to present their data during their studentship. To promote 'Open Access' publication, £148k has been awarded to members of SoLS since 2008, principally by RCUK and the Wellcome Trust. In other case studies Academic Presentation represents the first of a series of steps to generate impact.

One of the most common and effective approaches to generate Impact is Proactive Marketing, using television and radio broadcasting, web-based media, and social networking. This approach was used very effectively in the 'Reducing Healthcare Acquired Infections' and 'Early Cancer Detection' case studies to promote public awareness of healthcare issues. Assistance in these cases was provided by the university's Marketing Communications and Recruitment (MCaR) team,

which acted as liaison between the media and academics to promote public engagement, showcase academic expertise and disseminate research. Importantly it also provided media training courses for staff. The MCaR team is multi-disciplinary and highly regarded in the sector, having won more than 35 national and international awards over the past three years. They actively promote research activity via publications, media, video, social media, photography, TV/radio interviews, the web and blogs. Media coverage impact rates are consistently in the top 30 universities globally, with items reaching over 150m people per month. The MCaR team comprises 30 full and part-time marketing and communications staff with an annual budget of just under £1.5 million. Francis Gilbert also used Proactive Marketing for the 'Conservation Biology' study but by a very different route. He established a base at the Egyptian Ministry of Education to generate educational materials and promote conservation studies. This proximity to government was important as it facilitated media exposure through the public sector and led to adoption of the critically endangered Sinai Baton Blue butterfly as a conservation icon with specially printed Egyptian stamps bearing its image. In this case, travel funds and sabbatical leave for Francis Gilbert was funded by the university to enable this opportunity.

The Planned Exploitation approach demonstrates the commercial awareness of SoLS researchers. Spin-out companies have been established, e.g. CellAura (Fluorescent Ligand Technologies), Oncimmune (Early Cancer Detection) and NutraMet (Sports Nutritional Supplements), into which IP generated by the founders was transferred by the university for commercial exploitation. This created variously: revenues for the companies and the university, employment opportunities for new staff, and ultimately benefits for the businesses, patients and individuals to whom the technologies are targeted. Support for commercial exploitation was delivered by the Technology Transfer Office (TTO) and the Business Engagement and Innovation Services (BEIS) team, who provided assistance with IP protection and legal support for Confidentiality, Materials Transfer and Licence Agreements. A Business Development Executive embedded within SoLS also provided an interface with academic groups to aid successful commercial approaches. BEIS is a substantial department with 41 staff and an annual budget of £3.1m from HEIF, of which £1.6m per year is invested in projects across UoN, including £2m over the next 4 years in Hermes fellowships to support outreach, innovation and engagement activities. BEIS were also awarded follow-on funding of £100k in 2013 through the BBSRC Sparking Impact scheme, to facilitate knowledge exchange for researchers to test the commercial potential of their discoveries. The university has supported the foundation and spin-out of its start-up businesses, through Innovation Board seed investment funding of over £330k since 2011 (managed by BEIS), as well as contributing to the £10m Lachesis investment fund for a consortium of 8 East Midlands region universities. The university has invested significant sums in Oncimmune (£2.4m direct investment and £309k via Lachesis), which has leveraged £27m from venture capital and private sources. Similar BEIS involvement has facilitated development of CellAura Technologies with university investment of £147k and Lachesis funding of £350k to leverage £1.59m from venture capital. Furthermore, BEIS offer assistance with Technology Strategy Board and other similar government funding schemes for small businesses, of which more than £175k has been awarded to researchers in the unit since 2008. The university also allows founder-researchers to devote 20% of their time to take up Director or Consultancy roles for the company, and incentivises founders with a university revenue sharing scheme. These policies are key to the success of spin-out companies. Planned Exploitation has also been used to generate 'not-for-profit' healthcare benefit (e.g. 'Human Genetic Disorders') by making reagents freely available to healthcare diagnostic facilities worldwide.

A significant proportion of the SoLS research portfolio is supported by industrial partners (£6.5m funding, equivalent to 13% of research income, 20 RCUK-partnered CASE studentships and 17 industry-funded studentships since 2008). It is therefore unsurprising that Partner-Directed approaches are also a significant part of the SoLS impact strategy. Knowledge created by partner-funded research has been exploited by partner companies, and/or under licence to other companies, to develop commercial benefits. For instance: directed research funded by Esteve, GSK and Hoffman-La Roche is leading to new drugs for cognitive impairment ('Drug Target Validation'). Research funded by Morvus Technologies has facilitated superbug *C.difficile* toxoid vaccine development by Pfizer and ongoing anti-cancer therapeutic developments, as well as methods for biofuels production and chemical synthesis ('Bioengineering of Clostridia'). Funding from GSK led to improved sterility of food and beverage manufacturing facilities as well as

enhanced biochemical and nutrient additives manufacture ('Industrial Process Enhancements'). Support from the TTO and BEIS has been essential to manage the legal agreements between the academic and industrial partners. For instance, there are over 250 material transfer agreements, 5 licence agreements and 3 patents associated with 'Bioengineering of Clostridia', 7 patent families (170 national patents in total) associated with 'Early Cancer Detection', and 4 patents, a technology transfer pipeline agreement, and agreements covering cell-lines and reagents associated with 'Fluorescent Ligand Technologies', all managed by BEIS. Service in an advisory capacity for the industrial partner (e.g. Minton on the Scientific Advisory Board of LanzaTech, Fone as an advisor for cognitive research at Esteve and Ian Macdonald as an advisor to Mars and Coca Cola) also fosters and sustains successful industrial partnerships.

c. Strategy and plans

Promotion of research impact represents a strategic priority for SoLS and this is being developed using several approaches in parallel. We have established two mechanisms to strengthen the linkage between individual academics and the university BEIS department. The first is via research groups, which meet on average once per month, to consider all aspects of research including technical issues, grant applications, manuscript production and commercialization. The second mechanism to promote impact is through the annual activity review process for academic staff. Thus, each year all research active academics are challenged to consider their research plans and the impact of their research as part of the annual activity review. This involves not only identifying the potential impact and beneficiaries of the research but also proposing a plan to bring the impact to fruition, which is implemented and reviewed regularly at the monthly research group meetings.

Projects with commercial potential are reported to Jonathan Ball, who chairs the SoLS committee for IP and Commercialization (which includes representatives of BEIS) to facilitate commercial development. Where necessary, other appropriate groups within the university, such as MCaR for media and publicity, are also involved. Interaction with commercial partners is supported by Business Development Executives from BEIS, one of whom (Laurence Gardiner) is based full time within SoLS and is tasked with responsibility for ensuring commercial interactions proceed successfully. In addition to considering impact at research group meetings and as part of the annual activity review process, we have also started to hold half-day research forums every two months to facilitate scientific exchange and we plan to incorporate 'enabling impact' as important components of these meetings. Visiting speakers will be invited from potential commercial and other beneficiary groups, to help expedite future impacts. We are currently developing a research showcase event, to which potential commercial research partners are invited to facilitate collaboration and to develop future impacts. The event is being organised on a Faculty-wide basis to promote multidisciplinary research partnerships and strategic alliances.

In addition to supporting academics for development of impact we will also hold an annual session/meeting for postdocs at which impact is an important component. Although we do not anticipate postdocs will deliver impact independently of academic staff, we consider this training will improve their perception of research impact, whether to the benefit of on-going projects in SoLS, or for future projects when they achieve independent positions at Nottingham or elsewhere.

Strategic review of the research portfolio has identified a number of projects that are at a relatively early stage of development but which are likely to have impact in the future. This includes; GPCR drug discovery (Baker and Hill), Hepatitis C therapeutic antibodies (Ball), early Alzheimer's detection (O'Shea and Morgan), and therapeutic compounds for myotonic dystrophy (Brook and Hayes [Chemistry]), all of which have been supported by either the Wellcome Trust Seeding Drug Discovery Initiative (SDDI) or the MRC Development Pathway Funding Scheme (DPFS); some also benefit from investment through the university Drug Discovery Initiative. Additional projects with possible future impact include the development of rapid, point-of-care diagnostic tests for *Onchoceorca volvulus,* the parasite causing river blindness (Bradley), and *Schistosoma* species, which cause bilharzia (Doenhoff). The application of latex as an anti-helminthic and the use of IL6 receptor blockade for treatment of TNF receptor associated periodic syndrome (Tighe) are also projects with potential for future impact. These areas represent the focus for internal investment and prioritization to ensure that impact does ensue. Outreach and knowledge dissemination via the media and committee service will continue to be supported by the university.

d. Relationship to case studies

The case studies described in this submission have employed four general approaches to generate impact; Academic Presentation, Proactive Marketing, Planned Exploitation and Partner-Directed methods. No formulaic route to impact has been developed and most often combinations of these have been adopted. For several of the case studies beneficiaries were first engaged and impact initiated by Academic Presentation at scientific meetings. In the 'Biased Signalling' case, concurrent publication of research findings by SoLS and two other groups worldwide fundamentally changed a central tenet of GPCR pharmacology. The research significance was recognised and exploited by the pharmaceutical industry (e.g. Novartis) and allied reagent and service providers (e.g DiscoveRx), leading to follow-up collaborations to develop new screening technologies.

The 'Fluorescent Ligand Technologies', 'Drug Target Validation' and 'Industrial Process Enhancement' case studies similarly began with academic publication and presentations that generated interest from industrial researchers. However, SoLS researchers also undertook Proactive Marketing approaches, seeking invited seminars and business meetings with potential industrial beneficiaries to disseminate scientific advances in a more targeted manner. This either established the commercial value of the technology for subsequent Planned Exploitation (e.g. creation of the spin-out company CellAura Technologies), or led to industrial support for further Partner-Directed exploitation (e.g. testing 5-HT_6 antagonist drug candidates for cognitive impairments in Alzheimer's Disease and schizophrenia with Servier and Hoffman-La Roche, utilising insight of fungal biochemistry to benefit manufacturing process with GSK and improvement of nutritional supplements with DSM). Further examples of case studies using Proactive Marketing are the 'Reducing Healthcare Acquired infections' and 'Sports Nutritional Supplements'. In the former, media coverage involving public figures such as the actress Leslie Ash (herself a victim of hospital acquired infection), Andrew Lansley (at the time Shadow Health Minister), and Prof Dame Sally Davies (R&D Director of the NHS, now Chief Medical Officer for England), was used to raise public awareness of healthcare-acquired infections and provide political leverage to drive government healthcare policy changes. Support was provided by the university's MCaR department to promote public engagement and present media training courses for staff. In the 'Sports Nutritional Supplements' case, multiple presentations on creatine supplements for sports nutrition were given to athletes and coaches at the highest level of sporting excellence (e.g. Premier League football teams and sports advisory bodies including UK Sport and Sports Dieticians) right down to grass roots clubs and schools. These interactions resulted in transfer of university IP to MuscleTech Inc, from which a world-leading creatine nutritional supplements product range was generated.

The Planned Exploitation approach is encapsulated in the 'Early Cancer Detection' study for which the university founded Oncimmune to commercialise the IP from research to develop a blood test that allows lung cancer detection much earlier than other tests. In this case publication of key research outputs was delayed until patent publication to protect the commercial value of the IP, which in turn generated investment to drive development of the test, and subsequent clinical trials to show the patient benefit. In a similar vein, but with a more societal than commercial benefit, the 'Human Genetic Disorders' diagnostic testing case engaged with patients and families worldwide to develop genetic tests for inherited human disorders: myotonic dystrophy, Holt-Oram syndrome and campomelic dysplasia. Gene identification and analysis of genotype/ phenotype correlation in patients was critical. For knowledge transfer to healthcare professionals, the Proactive Marketing strategy of presentation at scientific meetings was adopted. Materials to conduct the tests were distributed freely to diagnostic test centres across Europe and beyond.

Much of the research within SoLS is 'blue skies' and our approaches to generate impact have followed several paths. The varied routes to impact have informed our ongoing strategy, which consequently embraces this diversity. It is clear that impact can stem from high quality grant-funded research alone, but importantly industrial partnerships, commercial expertise and support, and in some cases good media promotion, are also required to exploit more effectively the outcomes of our research. Although the approaches described here represent essential components to deliver impact, the single most important element remains the scientific ability and determination of talented individuals within SoLS.