Irish Contributions to International Science

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1. Introduction

The university as an institution has evolved to embrace three components: teaching, research, and technology transfer. Our review of the current state of Irish science will be mainly focused on research and essentially university research. Axiomatically research has to be taken in the international dimension.

We approach this survey of Irish science with more than one eye on the future. We will draw conclusions – some conclusions – based on discussion of the present and recent past. The present in Irish research is still drawing benefit, and inheriting more problematic aspects, from the Celtic Tiger period. Irish economic growth during this period, from approximately 1993 to 2001, averaged 9% per annum, and to date since then has continued to out-trump other national growth rates in Europe. This has had major positive implications for the financing of, and direction of, Irish science. The natural next question is where to next? The economist will have one answer to this question, and the social scientist may have other important considerations to raise. A necessary task though is to root future Irish developments in the evolution of science itself. This will be done primarily from the platform of the author's expertise in computing and allied mathematical sciences, – the new science of information.

Since sustainability of Irish research output, with a base that was strengthened by the Celtic Tiger period of outstanding economic growth, is one objective shared by all, we have to look a little at how the Celtic Tiger period came about. We will also gain from drawing conclusions from high points of Irish science in earlier times. The historian Eric Hobsbawm has characterized the 20th century as the "Short Century". The history of that century has a sharp change-point in August 1914, with the beginning of essentially three decades of war in Europe. A turning point marking the end of much that happened in the awful period of war and destruction came around 1989 with the "fall of the Wall" and the implosion of the Soviet economy. For Hobsbawm therefore, the Short Century was roughly the period 1914 to 1989. Roughly too, this period corresponds to the birth and early period of consolidation of the Irish state, up to the Celtic Tiger period.

The notion of a "Grand Challenge" has been quite widely used in recent decades. Leading models for past grand challenges have included the Manhattan Project, or John F. Kennedy's project to go to the Moon, or more recently the Human Genome Project. A number of grand challenges in science, mathematics and engineering in Ireland in the Short Century will first be reviewed. We will point to the international dimension, the driver and enabling role of the State, linkage with Irish universities, and aspects of the science.

In a sense this article is written in a way that is reminiscent to what the wavelet transform in signal processing does to a data stream: it decomposes the data into a background trend component – the DC or direct current component – and the foreground, superimposed, detail signal components – analogous to AC or alternating current components. In discussing the Ireland of the last century, and in presenting a short explanation as to how the Irish Celtic Tiger period came about and its links with science, we will be describing background phenomena that will help to profile some of the events of importance to us. We would like to look for long or Kondratieff waves in the Irish economy and in related scientific, technological and cultural expression, but such a study will have to wait for another day.

2. Shannon Scheme: A Grand Challenge at the Birth of the New Irish Free State

Ernest Walton was Ireland's one Nobel Prize winner in science. His first lodgings when he started work at Rutherford's Cavendish Laboratory in Cambridge in 1927 had electric fittings for light only and not for cooking or wireless, and for the light he had to pay extra[1]. The establishment of the Irish Free State in 1922 involved meagre resources, not least for science (non-existent) and engineering. Power networks were available in large population centres, but the new Irish Free State had the lowest per capita consumption of electricity in Europe, save only for Portugal.

Thomas McLaughlin, vintage Drogheda 1896, completing a BE in University College Galway in 1922 and PhD in 1923, was influenced by Frank Sharman Rishworth, Professor of Civil Engineering, in unwavering belief in the potential of the River Shannon as a source of hydroelectric power[2]. With an aim of contributing to the new Free State, he took a post with Siemens in London, and then in Berlin. He studied there the design of power plants, manufacture of electrical machinery, and the problems of transmission and distribution of power. All across Europe national electricity networks were being established, targeted at economic regeneration and uplift. Lenin's famous dictum around this time was that "Communism equals socialism plus electrification". Hydroelectric power had been pointed to as feasible and desirable in earlier studies in Ireland going back to the mid-19th century. McLaughlin pursued his investigations and received support from Siemens in doing this. Returning to Ireland in December 1923, he availed of close linkage with Government ministers. A Government white paper was produced with backing from Siemens. It was not a one-way flow: in 1924 four private parliamentary bills were debated with the aim of hydroelectric power usage of the Liffey, the river of Dublin. McLaughlin's view of the Shannon as being in the national interest won out. He considered the issue of power management and in 1927 legislation was introduced for the first semi-state body, the ESB (Electricity Supply Board) of which McLaughlin became the first Managing Director. Semi-state organisations along this model were to play a pivotal role in establishing an industrial base for Ireland in the Short Century.

Power from the Ardnacrusha Shannon site was online from 1927. Standardization was then needed for equipment, electric current, marketing to the consumer, rural (completed in the late 1940s) as well as urban access. McLaughlin was to resign as Managing Director in 1931, as a byproduct of the (necessary) overturn of the engineer in favour of the accountant, but remained as a technical director of the ESB for a further 25 years. Seán Lemass, who was to play a central role in economic policy for many decades, on behalf of the new Fianna Fáil Government in 1932 re-appointed him to the ESB Board. By the 1950s, Lemass ended the protectionism of the earlier decades and initiated the new economic policy that gave rise to the Celtic Tiger period of 1993-2001.

In the words of one commentator regarding the Shannon Scheme, never before was such a national financial risk of such proportions undertaken. Work began in 1925 and at its peak in 1928 employed 5000 workers. Accommodation was provided for many. One hundred kilometers of railway track was laid. Many freight ships were used, to bring in much specialized earth works equipment. Work was completed in about four years, and the Ardnacrusha plant was opened in July 1929. In construction and later, the Shannon Scheme and the ESB were major sources of employment. The project was a fortuitous event too for Siemens-Schuckertwerke in the post-World War I world. For Siemens it was the largest foreign contract awarded to a German firm since the construction of the Baghdad railway at the end of the 19th century. The total commitment of Siemens was striking. No resources were spared, and indeed financial losses were incurred, through tight Irish accounting.

We have noted how the vision and drive of McLaughlin was a prime mover of the Shannon Scheme, and we have noted the early influence of University College Galway. The corporate linkage of Siemens was crucial. Other aspects were interesting too, such as the overruling of Department of Finance opposition. There had been no call for tenders. Cosgrave, the prime minister, simply indicated that no other firm had expressed interest. The Shannon Scheme was financed (£5.21 million, by Government Act in 1925) by public loans. Associated with the Free State Government, Éamon de Valera (1916 leader, leader of the loosing side in the Civil War, leader of the Fianna Fáil party, later Taoiseach, and President) initially saw the Shannon Scheme as a white elephant but later gave it his full support.

Engineering and science, industry and Government were united in the Shannon Scheme project. The same was also manifest in another project of epic proportions started a decade later, which we will turn to next.

3. Peat: International Scientific Influence and Government Backing

In the previous section we have described the origins of the semi-state national electrical power utility in the newly nascent Irish Free State. Now we will describe the origins of another semi-state, also linked to the power sector. In both, grand challenges were addressed and solved, the State played a crucial role, and international science linkages were instrumental in all of this.

The years from the insurrection (1916 Rebellion) in the midst of the First World War up to the Civil War in 1922-23 were times of intense disturbance and upheaval in Ireland. Following the Civil War, C.S. (Todd) Andrews, who was to play a pivotal role in many semi-state bodies over the following decades, was encouraged by Denis Coffey, President of University College Dublin, to resume studies in accountancy. In his autobiography[3], Andrews describes himself as a “typical product of UCD”, which in turn was a “high grade technical school”. McLaughlin who realised the dream of the Shannon Scheme and the ESB had been an acquaintance of Andrews in UCD, before McLaughlin went to Galway. In 1930, McLaughlin asked Andrews to take a post in the ESB as an accountant. As we have seen, accountancy had become sorely needed in the ESB. Andrews was Chief Accounts Inspector until 1933, bringing to bear (as he says in his autobiography) IRA (Irish Republican Army) organisational methods.

Turf had long been used as a source of fuel, and interest in reclaiming land for agriculture was also of interest at least since the early 19th century. Presentations were made to the RDS (Royal Dublin Society) by Professor Hugh Ryan on peat in 1907/1908. In 1918, Professor Purcell presented to the RDS a study of peat in the Canadian context. A Dáil Éireann (Irish Parliament) Commission in 1920, on this theme, was chaired by Hugh Ryan, and in 1922 he translated a seminal book by Hausding – an employee of the German Patent Office – on peat.

Against this history, and with shifting views by pivotal (post-1932 party of government Fianna Fáil) Government figures Seán Lemass and Frank Aiken, Andrews was asked to drive forward the development of national resources based on peat. He was to stay 25 years in what was initially the civil service based Turf Development Board, and later from 1946 the autonomous semi-state body, Bord na Móna. In 1935, missions were carried out to north Germany, and to Russia (Moscow, Leningrad). Close contacts were established, and there were further missions in later years. With German equipment and technical support, development work started in 1936, "as a crusade rather than a commercial project".

An Experimental Station was set up in Newbridge, Co. Kildare, in 1946, and the First International Peat Symposium in Dublin in 1954 had 200 delegates. It is interesting that conflict with the ESB was to lead to a solution involving some industrial and university links. After all, power generation through peat burning was, in some degree, in direct competition with hydroelectric and other sources of the ESB's power. Dependence on the ESB's national grid was to be decreased through briquette production. To fund this, Sir Hugh Beaver, managing director of Guinness's stepped in. Notwithstanding opposition by the Minister for Finance, the Govenent was forced to provide collateral for Guinness's support. Jointly, Bord na Móna and Guinness sponsored a Chair of Industrial Microbiology in UCD.

4. Irish Linkage with Early Molecular Biology, and Early Computing in Ireland

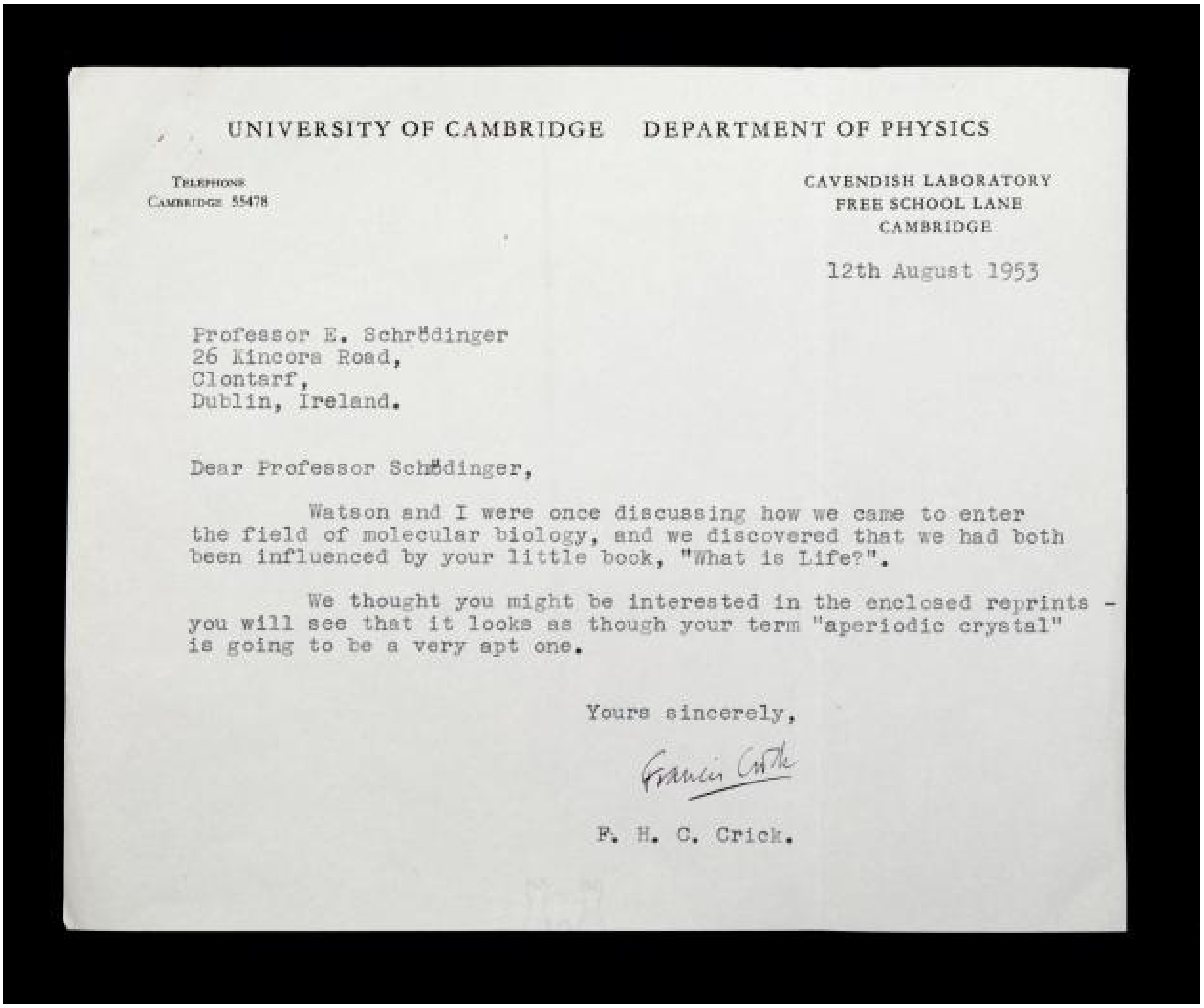
Once again illustrating active and progressive State involvement, the Dublin Institute for Advanced Studies was established in 1940 by Éamon de Valera who attended many seminars there.

Erwin Schrödinger was appointed first director of the School of Theoretical Physics in the Dublin Institute for Advanced Studies in 1940, and remained there until 1955. It is interesting to note that the discovery of the double-helix structure of DNA by Crick and Watson in 1953 was linked to lectures given by Schrödinger in February 1943 and published afterwards as a book[4], thus testifying to the mutually supporting roles of different disciplines of science. Figure 1 is interesting from the author's point of view too since some time after Crick and Watson's work he grew up a few streets away from where Schrödinger lived in Clontarf, and may – with a small stretch of the imagination – have observed from a baby's pram Schrödinger cycling past on his way into the Institute. Schrödinger's lectures, under the auspices of the Dublin Institute for Advanced Studies, were delivered in Trinity College Dublin in February 1943. In the book[4] resulting from these lectures, Roger Penrose in the foreword indicates how it "must surely rank among the most influential of scientific writings in [the twentieth] century", stressing in particular its "cross-disciplinary sweep".

Serving on the first Governing Board of the School of Theoretical Physics in the Dublin Institute for Advanced Studies was William McCrea. William McCrea contributed to the holding of the British Association annual meeting in 1957 in Dublin. We will return below to the life and work of another outstanding Irish scientist in the last century – John Bell – who contributed to the Belfast meeting of the British Association in 1988.

McCrea[5] was a distinguished astrophysicist, who became a Fellow of the Royal Society and received a knighthood. He was born in Ranelagh, Dublin, in 1904. He was brought up in England, and obtained a PhD in astrophysics in Cambridge in 1929. There followed academic appointments in Mathematics in Edinburgh and Imperial College London, before he became Professor of Mathematics at Queen's University Belfast in 1936. For interest's sake, Ernst Walton took up his studentship at the Cavendish Laboratory in 1927, and returned to a lecturing post in Trinity College Dublin in 1934. In 1944 McCrea moved to Royal Holloway University of London, and in 1966 to the University of Sussex. He died in 1999.

William McCrea's most important work was in solar physics and in relativity theory[5]. During his time in Queen's University Belfast, Armagh Observatory had been in decline, and Dunsink Observatory, then part of Trinity College Dublin, was practically closed. In the late 1930s, then Taoiseach de Valera was advised by McCrea. As a result Dunsink Observatory, located in north Dublin city, was reopened as part of the Dublin Institute for Advanced Studies.



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12th August 1953

Professor E. Schrödinger
26 Kincora Road,
Clontarf,
Dublin, Ireland.

Dear Professor Schödinger,

Watson and I were once discussing how we came to enter the field of molecular biology, and we discovered that we had both been influenced by your little book, "What is Life?".

We thought you might be interested in the enclosed reprints - you will see that it looks as though your term "aperiodic crystal" is going to be a very apt one.

Yours sincerely,

Francis Crick

F. H. C. Crick.

Figure 1: The birth of molecular biology – acknowledgement of lectures by Erwin Schrödinger, Director, School of Cosmic Physics, Dublin Institute of Advanced Studies, by Francis Crick, Nobel Prize winner with Watson and Wilkins in 1962 for the discovery of the double helix structure of DNA.

Interesting reminiscences by R. Johnston[6] include his links with the Dublin Institute for Advanced Studies, which lead on to description of the early days of computing in Ireland. In 1963 IBM's first realtime commercial systems in Europe were built with Aer Lingus. The first computer science department was in Trinity College Dublin, which John G. Byrne was to lead until his retirement in 2003. Early work by faculty in Computer Science in TCD was to run courses for senior civil servants, so that they could become aware of what computerization was all about[7].

5. The Irish Wirtschaftswunder

We have noted that the timeline of the Irish state up to the Celtic Tiger period of economic take-off was very close to the entirety of Hobsbawm's Short Century. While the unrest in Ireland began with the 1916 Easter Rising, this happened against the backdrop of hardly comprehendible slaughter in the trenches of the First World War battlefields.

Garret Fitzgerald, Taoiseach in the 1980s, has raised the interesting economic question[8] as to whether the unrest that gave birth first to the Irish Free State in 1921, and later through constitutional change in 1949 the Republic of Ireland, was necessary at precisely that time. Some ancillary questions were also raised. Were there particular weaknesses in the ties that bound Ireland and Great Britain around that particular period? And a question that has not been really addressed, and perhaps cannot be easily addressed: how do human and social actors perceive potential social change-points since, after all, such human and social actors do act rightly or wrongly on the basis of a perception or set of perceptions of the framework in which they find themselves. Men make their own history but not in circumstances of their own choosing.

Fitzgerald[8] points to how net inflow of state expenditure in Ireland was, around the 1916 period, soon to change substantially – and hypothetically – to the benefit of Ireland. Later, with the full development of the Welfare State in Britain, it would have been very difficult to countenance a breakaway of a major part of what had been Great Britain. In the period of the unrest that gave rise to the independence struggle there was a divergence in economic interests, in particular from the viewpoint of a largely agricultural Ireland, and a possible need for the industrial protectionism that came about after independence. Such national and state driven economic development became pronounced across most of Europe in the following decades, with the rise of fascist and communist – all protectionist and "national" – systems.

Fitzgerald's analysis[9] of the Celtic Tiger period from 1993 to 2001 – "a unique and unrepeatable boom" – is also thought-provoking. Up to 1995 there had been a rapid rise in exports to what is now the European Union (EU). This was in large measure due to US (and Japanese) inward investment to Ireland, with export of goods from the Irish base within the EU mainly in the computer and pharmaceutical sectors. Fitzgerald locates the boom in the ready availability of a highly skilled and honed, young workforce, available precisely when and where needed to take this export-led upturn on the hop, to the level of a boom. In the 1960s the Irish birth rate had been increasing, unlike elsewhere in Europe, and the educational level of the Irish young was much above the rest of the EU. Other factors complemented this picture: a large, available, skilled female workforce; high unemployment which was skilled and available for absorption into employment; and large numbers of recent (1980s) educated emigrants ready and willing to return to Ireland. Fitzgerald[10] sees the success of Irish inward investment and continuing international linkages, particularly in regard to the US, as being testimony to the solidity and quality of the Irish educational system.

Fitzgerald therefore solidly locates the great Irish economic boom of 1993 to 2001 in human capital. Going further though, he sees all essential factors as neither sustainable nor repeatable, with a falling birth rate, falling numbers in and less attraction towards education, and great decrease in unemployment.

At the time of writing, the jury is still out on whether Ireland's spectacular growth will continue. As the world slowly pulls out of the great recession that started in early

2001 Irish growth rates are above the European average. The educational system is looking a little wobbly, with numbers of students selecting key science and engineering courses on the decrease. High inflation for a period has gone right back to a very small amount. The threatened chaos of strikes in public transport, airport infrastructure, postal services, and health services, have at times been averted and at other times taken place but soon ended with what appears to be resolution. The bad public transport infrastructure – frankly unpredictable in view of such dramatic growth in the 1993-2001 period – is being addressed slowly but with commendable results.

Will Ireland's above average growth rates continue? This question is important for us because it impacts directly on government support for science. In our view there are other aspects of the current economic situation that should be taken into account, and which should not be discounted. These aspects are the purely scientific and technological ones.

The Irish *Wirtschaftswunder* in later years was closely associated with the dot-com boom. It was, after all, in areas of computing and biosciences that the international economic balloon was most manifest, as companies sought to use their own valuation as a tool to attract, or more often – defensively – to prevent, company take-over. Economic valuation became a means to an end, a marketing ploy related to the financial markets that had become of supreme importance in a world of shareholder value. The "new economy" was more open to playing such economic games, compared to more traditional sectors, although all were involved in the traditional sectors and the new sectors (Mannesmann and Vodafone, AOL and Time Warner).

If we seek to date the birth of the new economy in the area of computing and information science and technologies, perhaps no better date can be pinpointed than March 1993. This was the month that Marc Andreessen released the Mosaic web browser, the paradigmatic "killer app" of modern times. Almost overnight there was take-off of the World-Wide Web, hitherto one of a number of somewhat arcane protocols vying for attention in the sharing of digital information and knowledge (http, WAIS – Wide Area Information System, gopher, ftp and others built on them – archie, Veronica, and similar). The dot-com boom would not have happened were it not for Andreessen's work. And the Irish boom would not have happened without the computer industry. There are linkages here that lead us to the conclusion that one way to prolong Irish growth rates is through innovation in science and in particular in the "new information science" that underpins all others. Numerically and otherwise the weight of the Irish on planet Earth is not large, so that in the words of an Irish proverb, *An té nach bhfuil láidir, ní foláir dó bheith glic* – someone who is not strong had better be clever. We will return below to address this point of what is needed now in regard to innovation in key areas of science.

More secular problems for Irish science and technology are thrown up by the international economy. These include science's industrial linkages, Government funding, and the profile of science in the eyes of the young.

In our survey in earlier sections of some grand challenges addressed successfully by the new Irish state, we indicated how industrial linkage as well as that of Government were crucial. In Europe generally, though, the private sector is relatively inactive in supporting basic research. It is interesting to note[1] that in the work of Ireland's one Nobel Prize winner the Manchester-based company, Metropolitan-Vickers, played quite an important role in the development of Walton's and Cockcroft's equipment, enabled by Cockcroft's previous employment with them.

Based on OECD figures, Ireland does not spend much on R&D[11]: in 2001 the share of the Government budget allocated to indicators defined by the European Commission was 0.77% as opposed to Greece at 0.76%, Portugal at 1.47%, the EU average at 1.99%, Finland at 2.11%, and the Netherlands at 3.25%.

There have been swings of fortune in research funding in Ireland in the past years. The swings of the economy have meant too that student attraction in regard to science, informatics and engineering, have flowed and ebbed.

6. Scientific Cooperation in Europe

In recent decades, a specific area that is important for Irish science is that of linkage with international – mostly on the European level – collaborative research organisations. Such organisations pool resources in order to build expensive research infrastructure. Ireland belongs already to quite a few, and plays its role productively and to the full. Ireland still does not belong to some others, and it is our hope that such lacunae will soon be filled.

In 1954 CERN (Centre Européen pour la Recherche Nucléaire) was established in the field of high energy physics. It straddles the French/Swiss border at Geneva. It is a leader in high energy physics. It also gave birth to the World-Wide Web in that Tim Berners-Lee at CERN developed http (hypertext transfer protocol) around the start of the 1990s. CERN is now playing a leading role at European level in the development of the datagrid, i.e. the federation of massive distributed heterogeneous data collections. Ireland is not a member of CERN, and regrettably is unlikely to become a member soon.

In 1962, ESO (European Southern Observatory) was established first within CERN and then headquartered at Garching bei München, and over the following decades built and ran extensive observing facilities in Chile. There are a considerable number of astronomical observing facilities in the northern hemisphere, and the role of ESO was and is to have a planetary watch and observation activity in the southern hemisphere. The author served under Director-Generals of ESO who included Lo Woltjer, Harry van der Laan, and Riccardo Giacconi, – the latter getting a Nobel Prize in 2002 for his early work in high energy astronomy. Catherine Cesarsky is the current Director-General. Ireland is not a member of ESO. Astronomy is a field of "particular national strength"[12] in Ireland. Somewhat paradoxically it is not a field that has priority in any national Irish research plan.

The EMBO (European Molecular Biology Organization) in Heidelberg supports training and Ireland is a member. The complementary organisation, EMBL (European Molecular Biology Laboratory), also headquartered in Heidelberg, was set up in 1973. Ireland has recently joined EMBL. Particular research strengths of

EMBL are[12] gene function research, gene transcription, developmental biology, and bioinformatics.

Ireland also became a member recently of the European Synchrotron Radiation Facility (ESRF) which was established in 1988, and is headquartered in Grenoble. ESRF is involved in pure and applied X-ray photonic research. Applications are in physics, chemistry, materials and the life sciences.

The Georgia Tech appraisal study[12] of research organisations ranked these four inter-governmental, European, research organisations in terms of the full range of potential benefits for Ireland. In terms of highest ranked first, the rank order was: EMBL, ESRF, ESO and CERN. At the time of writing in early 2004, Ireland has now joined the first two on this list.

We will look briefly at a number of other important organisations at European level, and for which Ireland has long held membership.

The more basic science support organisation, the European Science Foundation (ESF), was set up in 1974 and is headquartered in Strasbourg. National member societies of ESF in Ireland are Enterprise Ireland, the Health Research Board, Irish Council for Science, Engineering and Technology (IRCSET), the Royal Irish Academy, and the Irish Research Council for Humanities and Social Sciences.

Collaborative European Economic Community – now EU – research policy was initiated with the Joint Research Centres, at locations that included Ispra, Petten, Geel and Karlsruhe. In terms of support for scientists across the European Union, COST (Cooperation in Science and Technology) is the oldest, and still functioning, programme. The first COST Actions were started in 1971. Later the Framework Programmes came about, beginning in 1983, and these strategic Europe-wide science and technology research and R&D programmes run at approximately four-year intervals. The Seventh Framework Programme is expected to start in 2006. Through membership in the European Union from 1973, Ireland has actively and beneficially been involved in the scientific cooperation embodied in all of these.

Ireland participates in Eureka, a European cooperation facilitator in the area of industrial research and development. Ireland has also long been a member of the European Space Agency, ESA, which unlike some other European-level research and R&D collaboration organisations, operates the principle of *juste retour*. This means that industrial contracts accruing to a member state are carefully benchmarked against national membership subscription contributions. In the period 1985 to 1999, it is estimated[12] that 38 Irish firms participated in ESA activities. Areas of such work included: communications, electronic components, precision engineering, software, and analytical services.

The author's Hubble Space Telescope (HST) work with ESA included considerable efforts in deconvolution algorithm development and deployment between the launch of HST by the space shuttle Discovery, mission STS-31, on 1990/4/25, the discovery of spherical aberration in the 2.4m primary mirror just after launch, and the first refurbishment mission by Endeavor, mission STS-61, in December 1993. If information has been lost through faulty telescope mirror construction there are limits to how far any computational approach can go in undoing the damage. Nonetheless deconvolution played its role in partially correcting the image data, and hence the faulty optics. Such algorithms are in constant use in generating interpretable images from raw medical data, in improving quality of surveillance imagery, and so on.

7. Science Foundation Ireland

In 2000, Science Foundation Ireland was established as a subgroup within Forfás, The National Policy and Advisory Board for Enterprise, Trade, Science, Technology and Innovation. It constituted the "largest investment in scientific research in [Ireland's] history"[13], with a € 646 million budget from the National Development Plan for 2000-2006. Its focus is on two areas, biotechnology and information and communication technologies.

The initial phase of SFI support for research in Ireland came in for considerable criticism by researchers in Irish universities (Stroyan[14], p. 96: points of criticism included funds allocated to physics under the heading of ICT; funds allocated to incoming SFI Principal Investigators rather than those already in the Irish system; and so on). Later SFI funding came to be more oriented towards those already in the Irish research system, and has now included taking over Basic Research funding from Enterprise Ireland. The latter continues to support commercialisation of research.

Computer science in Ireland is characterized by Stroyan[14] as "not the strongest from a purely scientific perspective", but good on the applied side. There is, this report indicates, "relatively little fundamental ICT research in Computer Science – industry collaborations and funding … dominate and drive research", which is not in itself a bad thing. The definition of ICT is broad: praise is given to materials research – magnetic materials, optronics – and physics-oriented, and Mathematics Department based, high performance computing. The report notes that Irish computer science is motivated and highly professional, and well linked with European Framework Programmes.

It is also stated that "An area of Irish strength is scientific computing, which appeared in many forms – sometimes appearing as inter-disciplinary scientific computing, or as parallel computing, or as basic applied mathematics". It does not appear to have been highlighted here nor elsewhere that this is precisely a key area of importance for Irish membership of European collaborative research organisations – EMBL, but also ESO and CERN. CERN is playing a leading role in datagrid projects, ESO combines virtual observatory and virtual data analysis with optics and photonics, and so on. Given the computing and instrumentation aspects of modern observational astronomy, it was not surprising that Finland's membership on ESO in 2004 involved a substantial contribution in person-years of software development.

SFI's initial phase was to inject fresh blood into the Irish system, essentially through the Principal Investigator programme. It then evolved into greater support for established researchers.

8. John Bell and the Greatest Achievement of Irish Science in the Last Century

We have deliberately held our discussion of the life and work of John Bell until we had first sketched out official Irish links with CERN, and also described current mainline Irish policy in regard to scientific research. The career of John Bell illustrates just how important an organisation like CERN plays in scientific achievement, and by implication its important role in Irish science. Furthermore, Bell's fundamental contributions to quantum theory, "the most successful scientific theory of all time"[15], has immediate and direct results in the new science of quantum computing and quantum information theory[16].

Bell lectured to the British Association meeting in Belfast in 1988. We have already seen that another great name of Irish science in the last century, William McCrea, had contributed to the British Association meeting in Dublin in 1957.

Bell ranked far and above all Irish scientists in the twentieth century. We make this claim not just because of his work in physics, considered as the "queen of the sciences" in the last century, his experimental work that was in a direct line of descent from Walton and Cockcrofts's work in 1932 (resulting in their Nobel Prize in 1951), and his productive intervention in quantum theory taking up earlier work of Einstein and Bohr. We also claim Bell as the greatest of Irish scientists in recent decades because of his contributions to the queen of the sciences in the current century, viz. the information sciences.

John Stewart Bell was born in Belfast in 1928. He entered Physics in Queen's University Belfast, first as a technician because he was a year too young to enrol, and completed experimental physics in 1948, and mathematical physics in 1949. Bell then moved to the UK Atomic Energy Research Establishment (AERE), Harwell, working in accelerator design, and more particularly modelling the paths of charged particles through accelerator detectors. This led to consultancy for the design of a Proton Synchrotron at CERN. Bell spent a year at Birmingham University, with Rudolf Peierls, and returned to elementary particle physics work at Harwell. His PhD was completed in 1956. In 1960, Bell moved to CERN. His work was directed towards high-energy physics and field theory. His most important contributions were in theory. He provided clarification on the Einstein-Podolsky-Rosen (EPR) paradox[17] which later was be applied in quantum computing and quantum information theory. Bell's contributions to quantum theory have been characterized as "the most profound discovery of science" (quoted in Whitaker[15]). In a career that was suddenly cut short, Bell died of a stroke in 1990.

9. The Institutional Framework: The Irish Universities and Institutes of Technology

There are seven universities in the Republic of Ireland (and two in Northern Ireland), and with these one should consider the Institutes of Technology, of which there are 13 in the Republic. The organizational frameworks of the universities and institutes of technology differ. We will express the view here that the lack of close research integration between the two sectors is a great pity, but we will not go into the reasons for this, beyond noting that there is far greater integration to be found in our European neighbours. We can consider the Fachhochschule in Germany, the Institut Universitaire de Technologie in France, and the “new university” in the UK, to indicate a few examples of perception which do not countenance sharp divisions.

Ireland does not have national research organisations governed by fixed annual grant allocations in areas such as computing science and engineering, physics and chemistry, along the lines of CNRS in France, CSIC in Spain, CNR in Italy, MPI in Germany, etc. However university-affiliated organisations have come to play an important regional role, e.g. the National Microelectronics Research Centre (NMRC) in NUI Cork, or the Research Institute for Networks and Communications Engineering (RINCE) in Dublin City University. In addition, the SFI Principal Investigator programme has similarities with CNRS research affiliation to host institutes.

Irish universities have not really had a good press. Narrating the story of Walton’s work on the splitting of the atomic nucleus in 1932 in Rutherford’s Cavendish Laboratory in Cambridge, and for which he and Cockcroft in late 1951 were awarded the Nobel Prize, Cathcart[1] says that Walton left the “scientific backwater” of Trinity College Dublin in 1927, and returned to the faculty there in 1934 with “a heavy teaching load [that] left him almost no time for research”. Lee[18] is scathing: regarding the National University of Ireland and Trinity College Dublin, he says that “it would be difficult to decide which of the two practised the more ambitious neglect [i.e. of building the Irish nation] in the first generation of independence”. Lee talks of “Irish retardation” in mobilizing the intellectual resources of the country, and points towards the administration of the universities. “Close examination of the performance of most presidents, provosts, registrars, finance officers and other relevant university officials has yet to be undertaken.” This is not entirely fair. We have seen that very important grand challenges were realised in the Ireland of Hobsbawm’s Short Century. Nonetheless it would be useful to have performance ratings openly and regularly published in the national press.

Of greater import is that the university as an institution is changing, and changing fast. Scott[19] points to how the modern university has come about by and large “alongside the idea of the state”. Universities that predated the state were fundamentally remoulded by the state. Even in the case of Oxford and Cambridge in the UK, Scott points to Royal Commissions in the 19th century, driving forward reform. The Humboldtian university, embracing research as well as teaching, was a central part of the modernization strategy of Prussia. The Humboldt ideal rests on three principles: the unity of science; the unity of teaching and research; and the essential paedagogical role of the scientific method. Land grant universities in the US were to promote agriculture. In a thoughtful essay, Scott (Vice-Chancellor of Kingston University) shows how universities have had internationalist agendas but in the national interest. Universities have shown themselves reluctant to engage in the fast-moving trend towards globalization. Current debates about increased fees to be levied on students – in Ireland as elsewhere – are part of this change of perspective on what the university is, and how it relates to other components in society (state, health sector, and so on). However for Scott the real challenge is not the New Economy but rather the New Culture of globalization.

The principal forms of Scott's New Culture are related to the Knowledge Society brought about by 21st century forms of globalization. These forms include "remorseless acceleration" of information and communication technologies; and the centrality of uncertainty and risk. Scott advances convincing perspectives on what this means for educational content. Research for Scott, however, is perhaps overly linked to the university's role in technology transfer, commercialisation, regional (re)generation, and wealth creation.

Comparative evaluation of research in Ireland is discussed in von Tunzelmann and Krameer Mbula[20]. The focus is on evaluation governance, i.e. structure of evaluation, control and process. A wide range of other countries are contrasted – Flanders (Belgium), France, Switzerland, Denmark, Norway, Sweden, Finland, Taiwan and elsewhere. While Ireland has approached international norms in science, technology and innovation, it is stated, it lags behind OECD (Organisation for Economic Cooperation and Development, affiliated to the United Nations) countries in evaluation. Inputs are quite well monitored, it claims, but not outputs nor impacts. From 1997, a quality assessment programme has been implemented in Irish universities, based both on self-assessment and external peer review. This quality assessment programme is called QAQI, Quality Assurance/Quality Improvement. A number of benchmarking studies have been carried out by ICSTI, the Irish Council for Science, Technology and Innovation.

However, while quantitative comparative evaluation of second-level education has been published in Irish newspapers, there has not yet been a ranking of Irish universities and university departments as there has been elsewhere (e.g. in the UK context in newspapers like the Guardian, or the Times; or in the German context in the weekly Der Spiegel). This should surely be carried out on a regular basis. Such rankings are beneficial for potential grad students, industrial linkages, international collaborations, and more.

In Europe-wide rankings Irish university departments have done well. In a Europe-wide comparative ranking of university departments by discipline in Der Spiegel, Electrical Engineering in University College Dublin came second overall in Europe. Stroyan et al.[14] point to two world-class departments in Ireland within SFI's biotechnology remit – Genetics, TCD, and Biochemistry, UCC. The 2003 "Academic Ranking of World Universities"[21] from the Institute of Higher Education, Shanghai Jiao Tong University, has been less happy for Irish universities, with none featuring.

It would be also interesting to have an explicit application of the UK's Research Assessment Exercise criteria applied to Irish universities, not least because it would provide quantitative comparative assessment with the two Northern Irish universities. Limited and all as any such quantitative assessment must be, it is widely recognized that it helps in imparting clear goals and objectives to all of those working in the system. It also lends some impetus to the clustering of expertise, and therefore is one way to tackle the disadvantage of lack of critical mass found at times for Irish research. Personnel movements between Irish universities and institutes of technology are rare and far between. (Here we consider the Republic of Ireland only; the situation is quite different in Northern Ireland.)

10. The Form of Output of Science: the Publication System

In previous sections we have essentially taken a top-down (governance, influence, motivation) perspective, or indeed an external-internal (social) perspective. From now on we will turn to a more bottom-up or internal perspective, – from the “coal face” as it were.

Our own view is that the changing times we live in offer new grist for the mill of the researchers. The social and institutional changes we are witness to can perhaps be used as a weapon to take on one traditional view of research, which is to dig oneself ever deeper into one’s specialism. Instead we counterpose Thomas Jefferson’s dictum that one should “Always work on important problems”[22]. As the Editor-in-Chief of one of the world’s leading computer science journals the author has from time to time to deal with a submission of impeccable credentials and presentation; but a judgement is not made easy if the author is the sole and unique world expert in this subfield, – leading on to the need for a judgement on the importance of the subfield.

Before taking a look at some aspects of international comparisons of Irish productivity in science, mathematics and engineering, it is useful for the general reader to point out that since about 1665 – for it was in that year that the journals *Journal des Scavants* in France, and the *Philosophical Transactions* in England, began – the yardstick of quality of research has been peer-reviewed journal publication. Unlike our colleagues in the social sciences, the book form of publication is far less relevant, with only the research monograph being of importance in science.

Between different fields the peer-review journal system can be quite diverse. We will take the cases of astronomy (say, the European journal, *Astronomy and Astrophysics*) and more methodological areas such as computer science, signal processing, or statistics. The author once marvelled at an announcement that referee review of submissions to a journal would be forthcoming within 24 hours: obviously the theme was an observational one, – astronomy, in this case. In statistics, or mathematical engineering fields, one could well wait for one year before the first round of referee reports. The *Computer Journal* has first round referee reports generally available with 6-7 weeks. In astronomy, generally there is one referee. In computer science and statistics, generally there are 3. The author, as Editor-in-Chief, did once have to handle a submission where there were 18 referees! Needless to say, decision-making is if anything made more difficult in such a situation. The custodians of research are the referees, and their role is an unpaid one, an unsung one and, nearly always, an anonymous one. Finding referees to match against a given journal submission is not an easy job: a typical rate of acceptance to do the job is 1 in 2. Helping this matching process is how researchers describe their expertise in their own web site – a widespread and near universal practice in North America, Europe, and Australia/New Zealand, but less so in East and South Asia. Clearly the entire practice of scientific research has changed totally since 1993, following the take-off of the web.

The changes brought about by the web and more particularly by content based access (through indexing engines such as Google) have had pronounced beneficial effects on the research system. Access to desired information has become, in many cases, immediate and quite high in precision. Because they are content-indexed, journals are far more useful online rather than on the library shelf. Pricing has become mainly institutional, with regional library consortia negotiating subscription prices for their (library) members. Most journals are now happy for authors to have their published papers additionally on their own web sites. Indeed the same is happening for books, with the online version raising the interest of the reader to proceed to buy the far more convenient form of bound printed copy.

Europe outperforms the US with 41.3% of the world scientific literature, compared to 31.4%. However on citation counts, the US is about one-third ahead[23]. A breakdown by field shows that the US and Europe are comparable in the earth sciences, mathematics and agricultural research. But US lead is evidenced in physics and medicine, and more so in chemistry and basic life sciences. In the computer sciences, the lead of the US, with Israel, is large. Among reasons advanced for why Europe lags behind[23], there is (i) lack of coordination and cooperation; and (ii) lack of critical mass.

The Georgia Tech study[12] of the potential in Irish membership through buy-in to European-level research organisations carried out a scientific productivity analysis in the relevant areas of science. Using the Science Citation Index, firstly authorship (at least one author) was sought where there was a link with the European research organisation. Considered were: CERN, EMBL, ESO and ESRF. Next, the most common keywords associated with articles authored in this way were found. Finally, Irish authorship was determined, based on at least one author being affiliated with an Irish institute. Ireland (based on the last criterion) produces 0.31% of all papers indexed by the Science Citation Index. The total numbers of papers found for CERN, EMBL, ESO and ESRF were, respectively: 111,422; 243,199; 19,368; and 189,937. The percentages of Irish participation in the fields represented by these organisations were, respectively: 0.28%; 0.33%; 0.39%; and 0.23%. Thus in molecular biology and more so in astronomy, Ireland by this analysis is over par. Cozzens et al.[12] also note that these fields are high impact fields in regard to Irish research output.

11. Current National Science, Mathematics and Engineering Priorities in the International Context: The Need for Grand Challenges

What Irish research science needs is one or more grand challenges, set by the research community, and serving to channel and focus not just research funding, but also the endeavours and energy of teams and individuals. The decadal plan in US astronomy has served to focus the community, raising challenges that are achievable, ranking facilities to be built, instrumentation to be developed, and approaches to knowledge discovery. Community cohesion helps to avoid the worst excesses of internal competition in proposal writing that is wasteful of precious time and energy.

We will focus our comments on the biosciences and on the computing sciences, since they comprise the major focus of Irish national policy in regard to science funding.

The information theoretic and computational underpinnings of the biosciences have been well-described by Kovac[24] (General Manager, IBM Life Sciences): "The bridges that are linking information scientists and technologists and biologists are growing stronger every day, and forming the basis for unprecedented scientific discovery". On the horizon is a humane and client-friendly health care system, an "information-based medicine", where medical treatment is no longer based on global "best fit" criteria, but instead is customized and indeed optimized for the individual's well-being and propensity to benefit healthwise over time. This is based on understanding of the individual genetic make-up and what results from this. It is backed up by industrial production approaches in medicaid that allow for individual optimisation rather that the traditional ensemble optimisation. The latter is acceptable to the economist, and has brought about inestimable gains through the improvement in public health (keyword: life expectancy) in the past centuries. However the former – "personalized optimization" – is also economically important.

In most respects the biosciences have as underpinnings the computer and information sciences. It is information science, after all, that handles real-world phenomena and observables, but additionally human cognition and perception are based on information in its myriad forms. It is these that are fundamental to human thinking, and as such have primacy over all other sciences. Grand challenges have been launched in computer science in the US and in the UK in recent years. Among other areas, in the US, "Information Systems" and "Information Assurance" have been selected as areas of grand challenge. In the computer and information sciences, in general, there is less common focus than, for example, in the biosciences. However let us comment a little further on where Irish grand challenges in our social information infrastructure could be best pursued.

Unlike e-science and the Grid in the UK, aiming at the next generation Internet through jointly developed university/industial middleware platforms, there is no highly visible Irish national orientation. There is no national computing institute like INRIA (Institut National de la Recherche en Informatique et Automatique) in France, of the Fraunhofer/GMD in Germany. The "communications" in ICT is an anachronism from the dot-com days when telecommunications became all the rage for a period. The most striking manifestation of this was the enormous sums expended on buying 3G (third generation telephony) licences. Nicolas Negroponte of MIT's Digital Media Lab went on record at the time to say that 3G licencing amounted to selling off the irreplaceable communications heirloom of near future generations.

Computing science and engineering could be very validly associated with domains other than just communications, for example the neurosciences, cognition and consciousness; or biomedicine. The very success of computer science has at times been something of a problem. It has been held, for example, that the objective of artificial intelligence has not been realised. However, speech-based systems, responsive and interactive user interfaces, trainable learning machines, Bayesian reasoning and inference systems, have all entered the mainstream and thereby have ceased to be "artificial" in any way.

It is surprising in fact that no-one associates computer science with potential centre stage solutions for the burgeoning problems of the health sector in our society, or the less prominent but also problematic evolution of the education sector. Compared to these social challenges, communications in the narrow sense (mobile telephony for voice and data) is very limited. The European Framework programmes do target social goals. Design by committee though is not a recipe for clarity of resolve, manoeuverability is limited in the extreme, and there is minimal (if any) linkage with national funding frameworks. In association with recent work on Grid technologies, the "virtual organisation" has been advanced as an expression for e.g. a car producer with engineering offices in Germany and design studios in California. This too represents a potent grand challenge for science in our time.

An institutional framework issue, that is in a sense a grand challenge, is getting the mix right between innovation and intellectual property. US patenting is based on "first to invent" and not European-style "first to file". In the US, up to one year's grace period is allowed the inventor during which publications can be made. In Japan, the period is 6 months. In Europe, though, there is a ban on any prior publication[25]. We have more sympathy for the US system in that it does not lead to the polarity of open publication versus non-disclosure and/or costly filing that the European "first to file" system requires.

The Bayh-Dole legislation passed in the US in 1980 provided for university commercial exploitation of federally-funded work. It has frequently been pointed to as an important enabling basis for technology transfer and spinout from university research.

Our starting point has been that essential questions of the day have not – so far – been addressed in a way that would serve to stamp self-confident and authoritative direction on Irish research in relevant areas. We have tentatively raised as one possible grand challenge the full deployment of computer and information science perspectives on the burgeoning problems of the health sector (including[26] but not restricted to telemedicine, customized and individually optimised treatment, information content and services based on virtual environments and augmented reality, …). It is not our objective to draw conclusions on what form near future grand challenges could take. In this chapter we want essentially to raise the question: Will Irish science stake out a claim to unique, ambitious, challenging objectives, which will differentiate it from others elsewhere and achieve advanced levels of innovation?

Our survey of Irish science with its international dimension has taken us through various grand challenges. Some past achievements have been signalled. We have highlighted the constructive and indeed at times creative interlocking of the State, industry and scientific research. In describing current directions we have pointed to some curious gaps in coverage. Remedying these could well lead to improved social return. Furthermore linkage with possible grand challenges ensue. Community-inspired grand challenges would serve to provide leadership and to limit wastage in innovation, which constitutes *the* most important aspect of the Irish *patrimoine* (cultural heritage) in this period.

12. Conclusion

In our survey we have included mention of the contributions by McCrea and Bell to the British Association meetings in Dublin in 1957, and in Belfast in 1988.

We have seen how proactive State support has, at times, led to stunning research and engineering accomplishments in Irish science in the past.

We have seen too that current Irish research funding is focused towards computing sciences and biosciences. It is in these fields – not exclusively but in some measure with certainty – that we can expect great achievements in the coming years.

We have also noted Irish pre-eminence in scientific computing. It is strange that there is a major lacuna at the core of Irish scientific research: that Ireland still does not plays its rightful role in the European Southern Observatory (ESO), and in CERN, the European high energy physics research centre. The career of John Bell, the greatest Irish scientist of the twentieth century, should suffice to show the potential gain for young (and indeed older) Irish scientists. The sciences of the future that underpin all others, including physics and the biosciences, viz. the information and computational sciences, are integrally linked to the work of ESO and CERN in such areas as the datagrid and virtual organisations, and quantum computing and quantum information theory. It is to be hoped that this major gap at the core of Irish science will be soon filled.

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