IOP | Institute of Physics In Wales | Sefydliad Ffiseg Yng Nghymru

# Science, Technology, Engineering and Mathematics (STEM) skills

**Institute of Physics in Wales submission to an inquiry by the Enterprise and Learning Committee of the National Assembly for Wales.**

**A full list of the Institute's responses and submissions to consultations can be found at www.iop.org**

**November 2010**

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Siân Phipps
Clerk to the Enterprise and Learning Committee
National Assembly for Wales
Cardiff Bay CF99 1NA

IOP | Institute of Physics In Wales | Sefydliad Ffiseg Yng Nghymru

Dear Committee,

**Science, Technology, Engineering and Mathematics (STEM) skills**

The Institute of Physics is a scientific charity devoted to increasing the practice, understanding and application of physics. It has a worldwide membership of around 40 000 (with around 1000 in Wales) and is a leading communicator of physics-related science to all audiences, from specialists through to government and the general public. Its publishing company, IOP Publishing, is a world leader in scientific publishing and the electronic dissemination of physics.

The Institute of Physics in Wales welcomes the opportunity to respond to the Enterprise and Learning Committee of the National Assembly for Wales's inquiry into Science, Technology, Engineering and Mathematics (STEM) skills.

If you need any further information on the points raised please do not hesitate to contact us.

Yours sincerely

**Professor Manuel Grande**
Chair of the Institute of Physics in Wales

**John Brindley**
Director, Membership and Business

**What are STEM skills?**

Science, Technology, Engineering and Mathematics are frequently grouped together as STEM not necessarily because of the content of the subjects but because of the way of thinking that is required to be competent in any of the STEM subjects. Training in STEM skills teaches critical thinking and an important lesson in using knowledge and applying it in new ways.

## Education

Mathematics and Science are considered to be core subjects and have to be pursued in school to GCSE level. Science at school is taught in three subjects – biology, chemistry and physics. Some schools offer each science subject individually (where pupils get a separate grade for biology, chemistry and physics) but many schools offer science and additional science (where pupils are awarded 2 GCSE grades for a combination of the marks from the individual subjects which are studied in less breadth than when studied individually).

The number of young people choosing to study physics at 16–19 level has now begun to rise slowly, but, at their lowest, A-level entries had fallen by 40% since 1980. Figure 1 shows the trends in Mathematics, Physics, Chemistry and Biology from 1985 to 2010.

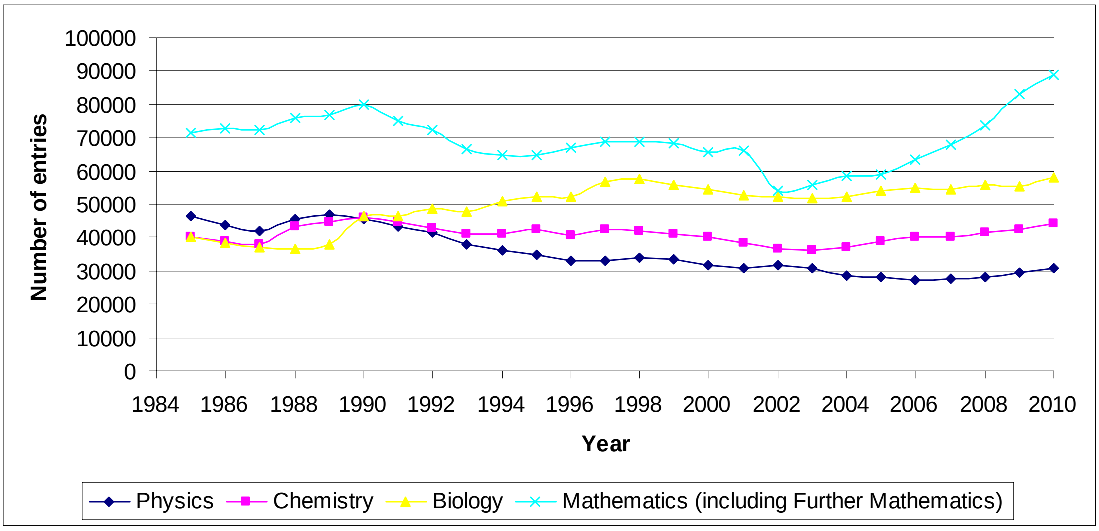


**Figure 1 – The number of entries to A-level examinations (including England, Northern Ireland and Wales) in sciences and mathematics 1985-2010**

The decline has been partly attributed to the advent of single- and double-award science GCSEs, which negated the identity of physics as a subject in its own right, as well as creating a situation in which specialists in biology or chemistry are required to teach the physics elements of science courses, despite their lack of any expertise in the subject. Added to this is a decline in the overall number of specialist teachers, as existing teachers retire and are not adequately replaced due to low levels of recruitment. It is estimated that the UK would need more than 700 new physics teachers every year just to stand still. In reality, fewer than 400 are recruited, and half have left after four years in the profession.

Each year the General Teaching Council for Wales (GTCW) produces an Annual Statistics Digest which provides information on the number of people teaching each subject. A large proportion of teachers teaching physics are not trained in the subject. From the GTCW statistics for 2010 there are 158 teachers teaching physics who were trained in the subject but there are 198 teachers teaching physics where their training was not in physics. The following table and pie chart illustrates the issue:

| | Number trained in subject | Number not trained in subject | Subject trained is unknown | Total teaching subject |
|---|---|---|---|---|
| Physics | 158 | 198 | 50 | 406 |

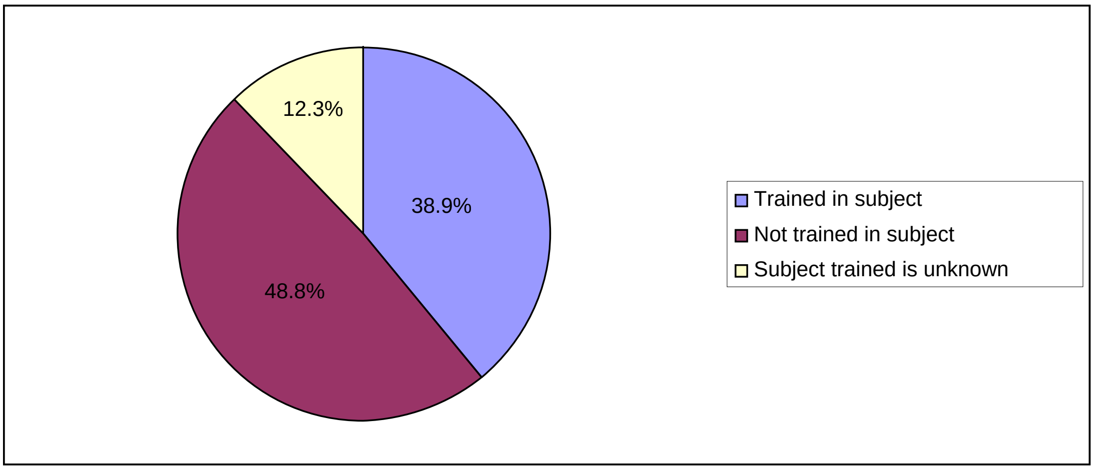


**Figure 2 – Number of teachers registered with GTC Wales by subject taught versus subject trained (secondary teachers only)**[1]

In the 2010 Annual Statistics Digest only nine newly qualified physics teachers were registered with GTCW (i.e., would have been Initial Teacher Education (ITE) subject trained in physics). To put this number into context – there were 45 newly qualified teachers registered with GTCW who were ITE subject trained in History.

The report 'Science and Mathematics Secondary Education for the 21st Century'[2] states: "The evidence from Ofsted is clear: teachers with specialist expertise in mathematics or the branch of science they teach achieve better outcomes in those subjects than teachers without".

It is therefore crucial that we increase the number of teachers with specialist expertise and fully support those teachers who are teaching outside of their specialism.

The Institute has produced a briefing note 'Physics and: Pre-19 education'[3] to highlight the concerns and statistics relating to physics education in schools.

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[1] GTCW Annual Annual Statistics Digest March 2010
www.gtcw.org.uk/gtcw/images/stories/downloads/Annual%20Statistics%20Digest/Annual%20Stats%2010%20%28E%29.pdf

[2] Science and Mathematics Secondary Education for the 21st Century
Report of the Science and Learning Expert Group, February 2010
http://webarchive.nationalarchives.gov.uk/tna/+/http://www.bis.gov.uk/wp-content/uploads/2010/02/Science-Learning-Group-Report.pdf/

[3] Physics and: pre-19 education An Institute of Physics briefing note, July 2010 www.iop.org/news/file_44103.pdf

Also, approximately a third of teachers registered with GTCW are over 50 years of age. The STEM community does have worries that this statistic may be worse for science.

## Continuous Professional Development (CPD)

It is widely recognised that the standard of physics teaching that students receive in school is a major influence on their decision to follow the subject at university[4]. With the majority of school pupils of age 14–16 being taught physics by teachers without a physics-related degree and with physics teachers often being alone in schools[5] the Institute of Physics set up the Physics Teacher Network to provide face-to-face support for those teaching physics. It is important that teachers undertake subject-specific CPD as teaching physics is not two separate disciplines, teaching and physics, but a combined one, physics teaching.

In Wales we currently have three teacher network co-ordinators who deliver a mixture of twilight sessions and day meetings which are always very well received by the teaching community. At the 9th Annual Welsh Physics Teachers Conference this year there were over 100 attendees including teachers, technicians, exhibitors and ITE students. The programme generally consists of examination bodies' workshops, an inspirational lecture on a modern physics topic (this year was the Bloodhound SSC Car) followed by practical workshops. The programme aims to provide teachers with experiences that will directly benefit their work as a physics teacher. As this model is "by teachers, for teachers" we believe that it is an excellent way of providing CPD. The expertise is already present in Welsh schools and this model of educational provision is also less expensive than the alternatives.

It is also crucial to support those teachers who are teaching outside of their specialism. The Institute of Physics has produced resources which support specialist and non-specialist teachers who teach physics in the early years of secondary education. There are materials for six topics available for teachers of the 11–14 age group and currently one topic for teachers of the 14–16 age group (more are under preparation). The resources are designed to help teachers gain a better understanding of physics, to allow them to experience for themselves something of its fascination, and to develop greater confidence in their teaching of it.

It is the Institute's view that the shortage of well-qualified physics teachers is by far the most pressing issue concerning physics in schools, and that the greatest amount of effort and apportioning of resources should be dedicated to solving the problem.

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[4] Woolnough**,** B. E., 1996, "Changing pupils' attitudes to careers in science"
*Physics Education,* 31 **(5)**, pp. 301-308
http://iopscience.iop.org/0031-9120/31/5/020
Woolnough**,** B. E., 1994, "Why students choose physics, or reject it"
*Physics Education,* 29 **(6)**, pp. 368-374
http://iopscience.iop.org/0031-9120/29/6/006

[5] Dillon, J., Osborne, J., Fairbrother, R., Kurina, L., 2000**,** "A study into the professional views and needs of science teachers in primary and secondary schools in England"
www.cst.gov.uk/reports/files/science-teachers/kostfin1.pdf

## Other issues affecting the uptake of physics A-level

First, it is well known that the take up of all STEM A-levels is significantly lower for students transferring from 11–16 schools to tertiary colleges than it is for their equivalents in 11–18 schools. One of the reasons for this is undoubtedly that the shortage of physics teachers is more pronounced in 11–16 schools where no A-level teaching is available.

A recent report, commissioned by the SCORE partnership (Science Community Representing Education)[6], has unequivocally shown that STEM A-level subjects, physics and mathematics in particular, are among the hardest at A-level, although Government and the Qualifications and Curriculum Development Agency (QCA) consistently assert that all A-levels are of equal difficulty, despite the lack of evidence to support that statement. In any case, physics and mathematics are perceived to be difficult. As a result, schools and colleges, with one eye on their position in the league tables, are reluctant to allow people to take these subjects unless they have an excellent chance of achieving high grades. Similarly, students themselves, perhaps unsure of their career path, are likely to choose subjects where they have a high probability of doing well. Unlike physics, most other university subjects do not require specific A-level subjects for entrance, but instead rely on the UCAS tariff. The tariff however does not distinguish between subjects; consequently, all the pressures on the school/college and student are pushing them away from physics.

## Monitoring skills level

Monitoring general skills levels is done by the Welsh Assembly Government through its Statistical Directorate. They have produced a report "The Levels of Highest Qualification held by Working Age Adults in Wales".[7] Even though this report looks at the attainment to different levels no mention of subject-specific qualification is made.

Wales should compare its STEM skills attainment to other nations and regions of the UK and internationally. Two international studies which are not based on examination results or qualifications are Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS). PISA is a survey of educational achievement of 15-year-olds organised by the Organisation for Economic Co-operation and Development (OECD)[8]. In 2006 Wales participated fully for the first time in the survey. The Achievement of 15-year-olds in Wales: PISA 2006 National Report[9] looked at the key results for science, mathematics and reading. It is reassuring to see that the mean score for science in Wales is not significantly different to the OECD average. While "Wales had a more consistent performance in

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[6] Relative difficulty of examinations in different subjects July 2008
CEM Centre
www.cemcentre.org/attachments/SCORE2008summary.pdf

[7] The Levels of Highest Qualification held by Working Age Adults in Wales, 2009
Statistical Directorate, Welsh Assembly Government
http://wales.gov.uk/docs/statistics/2010/101021sb872010en.pdf

[8] OECD Programme for International Assessment www.pisa.oecd.org

[9] Achievement of 15-year-olds in Wales: PISA 2006 National Report
http://wales.gov.uk/topics/statistics/headlines/schools2008/hdw20080311/?lang=en

Bradshaw, J., Sturman, L., Vappula, H., Ager, R. and Wheater, R. (2007). "Achievement of 15-year-olds in Wales: PISA 2006 National Report" (OECD Programme for International Student Assessment). Slough: NFER.
http://www.nfer.ac.uk/nfer/publications/NPC03/NPC03.pdf

the different aspects of scientific knowledge or skills assessed in PISA than that in many other countries", we also had "a wide spread of attainment compared with many other countries. While there were some at the highest level of achievement, there was a substantial 'tail' of low-scoring students." [9]

## Physics and Welsh

There has been a recent rise in the number of pupils studying physics A-level through the medium of Welsh. In 2000, eight examination centres and 43 candidates applied for WJEC A-level physics examination papers in Welsh. In 2009 that number had increased to 15 and 68 respectively[10]. In 2009, 4.6% of pupils who sat physics A-level took their examinations through the medium of Welsh.

Universities are beginning to respond to this, providing a progression for Welsh medium education. Aberystwyth University offers "Welsh medium modules" in both physics and mathematics.

[10] Nifer y canolfannau ac Ymgeiswyr yn Derbyn Fersiynau Cymraeg o Bapurau Arholiadau - TAG Uwch, Haf 2000, 2005 and 2009.
(Number of centres and Candidates receiving Welsh Versions of Examination Papers – GCE Advanced, Summer 2000, 2005 and 2009.)
www.cbac.co.uk/uploads/publications/10721.pdf

## Physics in higher education

The importance of scientific research has been reiterated by the Comprehensive Spending Review settlements, the National Infrastructure Plan and the support for STEM subjects in the Browne report[11].

There are three physics departments in Wales: Aberystwyth, Cardiff and Swansea. Each department has its own research strengths encompassing topics such as particle physics theory, astronomy and astronomical instrumentation, solar system physics, fundamental atomic physics and optoelectronics.

Two Welsh Institutions (Cardiff and Swansea) participated directly in the 2005 International Review of UK Physics and Astronomy[12]. This periodic exercise is co-sponsored by the Institute with the Royal Astronomical Society and the UK Research Councils which fund physics and astronomy research. Two of the general remarks from the report may be of interest to this inquiry:

"Curiosity-driven research is important in its own right and attracts the most able people into physics and astronomy, but it is also the foundation for the improvement of the quality of life and wealth creation in a knowledge-based society. The Panel has noted that some of the new money entering the science base has been tied up with specific initiatives. Many of these initiatives may be of strategic importance to the UK. However, the Panel is concerned that this could be a creeping trend that could undermine the opportunities of physicists and astronomers to follow their instincts in research, and the UK's ability to pursue curiosity-driven research at the highest level. The Panel recommends that the research councils monitor the balance between targeted and curiosity-driven research to maintain a healthy balance between the two funding streams."

"The Panel is of the view that physics has a unique place in a knowledge-based society, as a discipline that underpins the other core sciences and engineering. The Panel is deeply concerned that physics has ceased to be an identifiable discipline in a number of UK universities. A continuation of this trend would threaten the UK's ability to produce the volume of physics graduates needed to compete on an international basis. The Panel is disturbed to find that the financial health of university departments is to a significant degree dependent on undergraduate numbers, which themselves depend upon career choices of young people in the secondary system. This is not a good basis for strategic planning of the science base."

We concur. The physical sciences and, in particular, physics, mathematics and computer science are the strategic disciplines that fundamentally underpin technology and technological advances. Unfortunately, funding their activities within the current UK Higher Education (HE) system is fraught with difficulties, which stands to jeopardise the national economy.

The IOP and Royal Society of Chemistry commissioned and published a report earlier this year titled "Follow-up Study of the Finances of Chemistry and Physics

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[11] Securing a Sustainable Future for Higher Education
The Independent Review of Higher Education Funding and Student Finance, October 2010
http://hereview.independent.gov.uk/hereview/

[12] International Perceptions of UK Research in Physics and Astronomy 2005
Physics and Astronomy International Review
www.epsrc.ac.uk/pubs/reports/Documents/PhysicsInternationalReview.pdf

Departments in UK Universities" [13]. The report showed that "on the basis of TRAC-based costs (Transparent Approach to Costing) the majority of chemistry and physics department for which full data were available in England were close to breaking even or even in surplus on total teaching activity. The lower level of funding for teaching per student in the departments in universities in the other countries of the UK generated higher deficits on teaching activity in these departments."

In the present HE funding climate it is important for Wales to review its funding of HE to ensure that it is adequately funding each subject (based on TRAC data) and to ensure that the Higher Education Institutions (HEI) in Wales are able to compete not only nationally but internationally. It is also important to have a look at the provision of physics across Wales both ensuring that students have access to a physics department and ensuring a critical mass of physics research in Wales

In future, inter- and multi-disciplinary research will be increasingly important in some areas (e.g., nanotechnology, nano-medicine) and in other areas generic new technologies will drive the science (e.g., visualisation). The strengths that expert physical scientists can bring to these emerging areas must not be underestimated.

**Diversity in higher education**

The majority of physics staff has always been male. However the overall proportion of female staff continues to rise, with women now occupying 12% of staff positions, as compared with only 9% in 2004. However, this proportion is still low in comparison with overall HE figures. In terms of new appointments, the field of astronomy, astrophysics, cosmology and space physics is notable because almost 25% of arriving staff members are female (27 of 111)[14].

Project Juno[15] was established by the Institute in 2007 in response to best practice identified from the Institute's "Women in University Physics Departments: A Site Visit Scheme", which ran from 2003 to 2005. The aim of Juno is to recognise and reward departments that can demonstrate they have taken action to address the under-representation of women in university physics and to encourage better practice for both women and men. By being awarded Practitioner or Champion status, a department's best practice and contribution to increasing the representation of women in physics will be publicly recognised. There are three levels of Juno awards: Supporter, Practitioner and Champion. The Institute currently has 30 physics departments engaged in Juno, with three Champions, seven Practitioners and 20 Supporters. One department from Wales (Swansea) is a Supporter.

The Institute published a digest 'Diversity in University Physics Statistical Digest 2010'[16] providing a concise overview of the diversity profiles of academic staff in university physics cost centres in 2007/08 in the UK. This digest includes data on the

[13] Follow-up Study of the Finances of Chemistry and Physics Departments in UK Universities
An Institute of Physics and Royal Society of Chemistry report June 2010
www.iop.org/publications/iop/2010/file_43926.pdf

[14] Survey of Academic Appointments in Physics 2004-2008 www.iop.org/publications/iop/2010/page_38419.html

[15] Project Juno - www.iop.org/policy/diversity/initiatives/juno/index.html

[16] Diversity in University Physics Statistical Digest 2010
www.iop.org/publications/iop/2010/page_43857.html

nationality, ethnicity and age of staff in physics cost centres. In general, there has been a complex picture of retention and attrition among different ethnic groups in physics, from A-level through to undergraduate and postgraduate levels. The Institute, together with the Royal Society of Chemistry, has published research in this area[17].

## Physics degrees

The Quality Assurance Agency for Higher Education (QAA) produces benchmark statements for different subjects which describe the nature and content of that degree subject. The 'Physics, astronomy and astrophysics subject benchmark statement'[18] contains a list of physics skills and generic skills that physics graduates should be able to gain during their degree. The generic skills are problem-solving, investigative, communication, analytical, ICT (Information and communication technologies) and personal. These skills are not only of value in a physics-based industry or in academia, but are valuable in all sectors.

The Institute of Physics produces a document which details the skills and achievements that graduates of accredited degree programmes should have (The Physics Degree Graduate Skills Base and the Core of Physics[19]).

The Institute accredits UK physics degrees on a voluntary basis[20], and this programme to some extent provides a guarantee of a high-quality minimum provision in the subject, although there is still considerable variation. The recent experience of the programme is that, in general, physics undergraduate degrees in the UK are in good shape, and fit for purpose.

The Higher Education Academy (HEA) published its 'Review of the Student Learning Experience in Physics'[21], which provides a snapshot of the state of the student experience in UK physics departments in 2008. A reassuring conclusion from the report is that: "*84% of the undergraduates rate the majority of their teaching as "excellent" or "good" "*.

A concern is the impact of research assessment, where many staff with teaching interests have been made to feel second-class. Although some universities have now introduced teaching routes to chairs, the lack of an adequate funding stream and the culture of universities make it difficult for teaching and research to be seen on an equal footing. Departments should offer staff with teaching interests a realistic career

[17] P Elias, P Jones and S McWhinne, "Representation of Ethnic Groups in Chemistry and Physics", 2006, London: Royal Society of Chemistry and Institute of Physics, www.iop.org/publications/iop/2006/page_38240.html

I Springate, J Harland, P Lord and A Wilkin, "Why choose physics and chemistry? The influences on physics and chemistry subject choices by BME students", 2008 London: Royal Society of Chemistry and Institute of Physics. www.iop.org/publications/iop/2008/page_38220.html

[18] Subject benchmark statement – Physics, astronomy and astrophysics www.qaa.ac.uk/academicinfrastructure/benchmark/statements/Physics08.asp

[19] The Physics Degree – Graduate Skills Base and the Core of Physics June 2010 www.iop.org/education/higher_education/accreditation/file_43311.pdf

[20] IOP Degree Accreditation www.iop.org/activity/policy/Degree_Accreditation/index.html

[21] Review of the Student Learning Experience in Physics, 2008 www.heacademy.ac.uk/assets/ps/documents/subject_reviews/physrev_final.pdf

progression. The Institute would like to see every department, certainly every physics department, having at least one member of staff specialising in teaching innovation, which is common practice in US state universities. Perhaps a more practical solution would be to encourage a community of such academics which can cater for a range of universities. Having someone active in pedagogy research available to a physics department would ensure contact with people active in frontline physics research. However, a way to pay for these academics would need to be determined, along with a way to effectively accommodate them in future research assessment exercises.

Following the announcement of the Browne Report there has been considerable media coverage given to discussion about funding of undergraduate courses. It is essential that there is a system of charging that is not financially disadvantageous to those who study subjects like medicine, engineering and laboratory-based sciences such as physics and chemistry. In addition, for subjects like physics, chemistry and engineering a significant fraction of the undergraduate cohort is enrolled on four-year courses, so further financial pressures exist.

More information can be obtained from the IOP's response to the Independent Review of Higher Education and Student Finance[22].

The number of students accepted onto physics courses in Wales has increased significantly since 2000[23]. For the 2000 year of entry there were 112 successful UCAS applicants accepted onto physics degree courses in Wales. In the 2009 year of entry, 180 students were accepted onto physics degree courses. We are pleased with the increase and hope that this upward trend will continue. Any potential student cap should not be based on current undergraduate physics numbers but on the number that we would like to have and require in Wales. Comparisons could be made between Wales and other nations of the UK (per head of population). Considerable effort is being put into promoting studying physics at HE level and therefore it would be a travesty if students were being turned away from university physics departments because of an unintended consequence of a student cap.

A recent initiative, Stimulating Physics in Wales (funded by the Higher Education Funding Council for Wales and managed by the IOP) saw two teacher fellows being placed in two of the physics departments in Wales to look at easing the transition from school to university physics[24]. The departments have benefitted significantly from the contribution of the teacher fellows. One department stated that the teacher fellow's contribution "has given the staff in the University better insight into the likely physics knowledge of school leavers, the methods by which they learn at school and the anticipated level of their mathematical and practical skills. We intend making some changes to the curriculum and general teaching methods as a result." Another department is planning to introduce a new optional Level 3 module under the aegis of the Undergraduate Ambassadors Scheme (UAS), in which students with an interest in teaching can spend time working in local schools under the supervision of a Teacher/mentor. The teacher fellow had taken a lead role in making this happen.

[22] Institute of Physics response to Independent Review of Higher Education and Student Finance, January 2010
www.iop.org/policy/consultations/higher_education/file_41881.pdf

[23] UCAS Statistics Online
www.ucas.com/about_us/stat_services/stats_online/

[24] Stimulating Physics – The Teacher Fellowship Scheme
www.stimulatingphysics.org/the-pilot-teacher-fellowship-scheme.htm

**Postgraduate education**

There are multiple benefits to postgraduate education, not only to the individual, but also to HEI, to business and to the wider economy and society. Individuals gain unique experience of leading-edge science and how to think originally and present ideas and results in a scholarly manner. All research postgraduates learn to manage their own time and also to communicate, which are important skills as well as increasing their knowledge base. Postgraduate education also opens up a broader, more lucrative job market. For the HEIs the first stages of career development for their establishments are under way thus leading to new cohorts of postdoctoral students (who are the workforce that help Principal Investigators undertake research), lecturers and professors.

It is important for businesses to have access to a range of highly skilled (and motivated) individuals capable of thinking 'outside of the box', particularly physics-trained postgraduates, due to the highly numerate, analytical and problem-solving skills that are acquired during their training. Without such an output of highly qualified people the economy would not grow. The UK depends on 'ideas' to keep abreast of its competitors.

An issue of concern is that there are only a few taught MSc programmes being offered by physics departments, primarily due to the fact that it is difficult to get sufficient funding to cover the costs. However, a report into the finances of physics departments[25] commissioned by the Institute revealed that, of those that have specialist taught MSc programmes, the courses can contribute significantly to the financial health of a department. The report recommended that physics departments need to examine their scope for running niche postgraduate taught programmes that may be able to command high fees from both home (sponsored) and overseas students, with appropriate support from the research councils.

The Institute's European links make us continue to be concerned that, post-Bologna, the UK as a whole is not in tune with the other major European Union nations in terms of their HE provision. We already have evidence that the 7 year, or even 6 year period to achieve a PhD is not producing PhD graduates with skills at the same level as the equivalents in our European neighbours. Consequently, there are potential issues with the employability of UK PhD graduates and the attractiveness of the UK to international students.

[25] Study of the Finances of Physics Departments in English Universities, July 2006 www.iop.org/publications/iop/2006/page_38237.html

## Careers advice

It is imperative that an educated student market is created. A significant problem facing science, and particularly physics, is that students are making ill-informed subject choices between the ages of 12–15. Teachers, parents, careers advisors should be in a position to highlight the benefits and the wide variety of career options that are available through science. This might be achieved by a combination of approaches, including training of careers advisors (who tend to come from non-scientific backgrounds) and science teachers in careers. The Institute recognises that the need in schools and colleges is to promote opportunities across the whole spectrum of STEM and therefore careers work must be done in partnership. The Institute already works with other professional bodies to produce joint literature and attend events promoting careers from STEM.

An example of collaboration by the different STEM subjects is the website 'Future Morph'[26] which was launched by the Science Council in 2008. It was "set up to show that studying science, technology, engineering or maths beyond the age of 16 isn't just a one track road to becoming a scientist or engineer – the skills and knowledge you gain are valuable in almost any career and will make you very employable."

A recommendation from the Science and Mathematics Secondary Education for the 21$^{st}$ Century report states "All young people should receive planned systematic information, advice and guidance on STEM careers from KS2 (Key Stage 2). This should be integrated into science lessons and enrichment, rather than being an 'add-on', complementing the support provided by external services and specialist careers teachers". The IOP has developed a workshop 'Exploring physics, uncovering choice'[27] to encourage staff to work together in providing a consistent approach to careers advice and guidance in their school. It will also help teachers to build on their own knowledge of physics-based careers and in turn, help students to make informed choices based on accurate information.

As part of Stimulating Physics in Wales (an initiative funded by HEFCW and managed by the Institute of Physics) the Industrial Trust set up industry visits in North-East Wales where school pupils had opportunities to visit local industries to witness the role of STEM subjects in career pathways. The Industrial Trust working in partnership with Reaching Wider North Wales Partnership, Glyndwr University and Techniquest Glyndwr set up a STEM day in order to encourage year 9 pupils to see the importance of STEM subjects at college and university by showing them the relevance and career outcomes of STEM subjects. The day comprised of an opening lecture and a range of workshops from both academia and industry for which the school pupils were split into groups.

Careers advice should not be restricted to schools. Parents play a large part in the subject choices of pupils. There should be a wide-range of careers advice not just for STEM but across all disciplines and available in many locations so that everybody has an opportunity to make informed subject and career choices.

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[26] www.futuremorph.org/

[27] Exploring Physics, uncovering choice Workshop
www.iop.org/education/teacher/support/epuc/page_43564.html

## Physics in the economy

### Physics graduates

There are currently no reliable data on the career destinations of those who graduate from STEM degrees, or indeed any rigorous survey of the first degree subject by sector of the workforce. However, recent enquiries of the Institute's membership, the majority of whom hold an undergraduate physics degree, have suggested that physics graduates are employed in all sectors of the UK economy, in a diverse range of areas including law, healthcare services and the financial industry.

Within the wide range of occupations and roles in the UK economy, STEM graduates are commanding salaries above the national average. The Institute of Physics together with the Royal Society of Chemistry published a report, "The economic benefits of higher education qualifications"[28], in January 2005, which revealed that physics and chemistry graduates in the UK earn more than graduates from most other disciplines.

The report shows that over a working life, the average graduate will earn around 23% more than their equivalent holding two or more A-levels, compared with 30% more for physics and chemistry graduates. The figure of 30% compares with 13–16% for graduates in subjects including psychology, biological sciences, linguistics, and history. According to the report a graduate in physics or chemistry earns between £185000 and £190000 (compared with the average for holders of degrees of all subjects of £129000) more during their career than someone with A-levels but no degree, whereas history and English graduates earn between only £89000 and £92000 more. The report also demonstrates that physics and chemistry graduates pay approximately £135000 more in tax than those with A-levels alone and £40000 more than the average graduate during their working lives. Furthermore, the report assessed the costs associated with undertaking a degree, trading them off against the economic benefits. It concluded that the individual rate of return to the average degree holder, relative to their investment in terms of fees and lost earnings, etc., is about 12% per annum. This compares with an individual rate of return for graduates in physics and chemistry of 15% per annum."

As part of the Institute's 'Undergraduate Physics Inquiry' of 2001[29], a survey was undertaken of the views of employers of physicists. This pool of employers included those from finance and other service sector industries. The survey suggested that there is strong demand for physics graduates and that employers believe that physics degrees give:

- flexibility and versatility to tackle a wide range of technical and non-technical subjects;
- good analytical and problem-solving skills;
- good mathematical and IT skills;
- a good breadth of technical interest and ability;
- a good understanding of fundamentals from which to approach new situations where traditional approaches do not work;

[28] The economic benefits of higher education qualifications, 2005
Pricewaterhouse Coopers for the Institute of Physics and the Royal Society of Chemistry
www.iop.org/publications/iop/2005/page_38258.html

[29] Undergraduate Physics Inquiry 2001

- analytical problem-solving capabilities (in some sectors, including the financial sector, emphasis is put on the advantages of a research training in enhancing these skills);
- an ability to grasp concepts quickly and in a quantitative way (more important than knowledge of a particular specialism); and
- an ability ‘to argue on one’s feet’.

**Physics in the Welsh economy**[30]

Physics-based industries, where physics knowledge and expertise are critical to the survival of the businesses, make a substantial contribution to the economy of Wales. Physics-based industries contribute a greater proportion of wealth to Wales than to the UK as a whole. Between 2000 and 2005 physics-based businesses accounted for 14.2% of total national turnover compared with 8.6% in the UK.

This comparatively high level of turnover generated in physics-based sectors is reflected in higher levels of turnover per employee in the sector. The turnover per employee between 2000 and 2005 in physics-based sectors was, on average, £214000 per annum. This is £141000 more than the Welsh national average where turnover per employee equates to £73000. It is also much greater than that of banking, finance and insurance as well as the construction sector in Wales. (The equivalent figure for turnover per employee in physics-based sectors in the United Kingdom was £165000 – the UK national average is £72000.)

Physics-based sectors in Wales account for (2005 figures):

- more than 50000 jobs, 4.4% of the workforce.
- £4.1 billion of GVA, 10% of total economic output of Wales.
- £13 billion in turnover, making up 14.3% of all total business turnover in Wales.
- High value jobs, the GVA per employee is £80000, double the national average in Wales.

While the majority of people working in physics-based sectors will not be directly engaging in ‘physics’ through their everyday work, the existence of the sectors (and so their jobs) is critically dependent on physics.

[30] The importance of physics to the Welsh Economy
centre for economics and business research ltd, 2007
www.iopwales.org/activity/business/index.html

**Innovation**

*If I'd asked my customers what they wanted, they'd have said a faster horse* [Henry Ford]

You cannot have innovation without science. One may comment that you can have science without innovation. However, that does a great disservice to the researchers who are doing blue skies research. Sometimes the applicability of an area of science may not be immediately relevant. For example, lasers were originally a solution that had no problem; the physicists who produced LCD screens were not those scientists that were working on producing smaller screens. It is notoriously difficult to predict scientific breakthroughs. Therefore, it is counterproductive to fund only research which is perceived to be of immediate public benefit.

However, there must be structures in place to facilitate collaboration between industry and universities. Sometimes it takes a fresh eye to see how a solution can be applied to a different problem.

One of the suggestions of the 'Lambert Review of Business-University Collaboration'[31] is "the most effective forms of knowledge transfer involve human interaction" shows that people are the most important part of the innovation equation. Schemes are run by the UK research councils for people to cross the divide between industry and academia. It is a disappointment that no university in Wales has a Knowledge Transfer Account or Knowledge Transfer Secondments and currently no Industrial Doctorate Centres. We should look into opportunities such as these and address the reasons why we are not obtaining these kinds of support. Is it because we are not applying, or that our applications are unsuccessful. We recommend that support is provided for universities in Wales to take advantage of sources of funding to enable the flow of people between academia and industry.

[31] Lambert Review of Business-University Collaboration, December 2003 www.hm-treasury.gov.uk/d/lambert_review_final_450.pdf

## Strategic policies

### Chief Scientific Adviser

The IOPW welcomed the announcement of a Chief Scientific Adviser (CSA) for Wales. This role has provided a much needed focal point for science and engineering in Wales.

### National Science Academy

The IOPW welcomed the announcement of a National Science Academy (NSA)[32]. We welcome the role that the NSA would have in co-ordinating current and future initiatives which promote the uptake of STEM subjects. There is already good practice occurring in Wales regarding co-ordination of activities. There are groupings of STEM individuals and organisations which share information regarding activities and resources. Two such groupings are Science Alliance Cymru (a grouping of those interested or working in public engagement related to STEM) and cydSTEM (a group which contains the IOP, the Royal Society of Chemistry, Wales Institute of Mathematical and Computational Sciences (WIMCS) etc). Therefore such a role of the NSA should build on the networks that have already been developed.

One large scale example was the Big Bang Wales which was project-managed by Careers Wales West, but with support from organisations such as ourselves, IT Wales, WIMCS etc. It was held at the National Waterfront Museum in Swansea and hosted over 400 young people from Pembrokeshire to Powyss and featured many exciting activities, from flight technology to racing cars. Designed to focus on the importance of STEM to society and demonstrate how the study of STEM subjects can make a real difference to the lives and future career opportunities of young people, this year's event was a resounding success. Over 50 teams and individuals from around 30 schools competed for a place at the National Big Bang event which will be held in London in 2011 with no fewer than 8 projects winning through.

Another example was the Urdd Eisteddfod in Llanerchaeron, Ceredigion in June this year. The science pavilion (Gwyddon*Le*) was filled with interactive exhibits, workshops and competitions. A grant was awarded by the STFC to the Urdd[33] for exhibitions and activities relating to astronomy and solar system research. Two of the activities combined physics and the arts. Following visits by physicists to a few primary schools in Ceredigion one school worked with a professional choreographer to create a creative dance based on the stars and the solar system, another school worked with an artist to create a 3D scale model of the solar system. Physics was not alone in the Science Pavilion – Aberystwyth's University's other science departments were represented, as were a number of companies and organisations – all providing exhibits, workshops and competitions for young people. There were approximately 10000 visitors to the Science Pavilion and it proved a hub of activity and fun throughout the week.

An example of co-working across the STEM disciplines on a yearly basis is the National Eisteddfod, where there is a Science and Technology central committee and a local science and technology sub-committee. Both work together in ensuring the success of the Science and Technology Pavilion which is always a hive of activity.

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[32] http://wales.gov.uk/about/cabinet/cabinetstatements/2010/100428nat/?lang=en

[33] Science and Technology Facilites Council, Funding for Public Engagement, Small Awards Scheme www.stfc.ac.uk/Public%20and%20Schools/13881.aspx

We were also reassured to see in the announcement reference to “encourage the take up of these subjects from primary school through to university level and overcome any barriers – perceived or real – that discourage learners from studying these key subjects”. Much work has been undertaken by organisations such as the Institute of Physics looking at what prevents certain groups from studying particular subjects. The Institute of Physics is keen to increase the diversity of students studying physics. In recent years, it has worked hard to understand the relative lack of participation of girls and students from ethnic minority groups.

Girls are under-represented in physics post-16. They continue to make up only 22% of those taking A-level physics, despite huge changes in the educational system over the last 20 years. Physics is only the 19th most popular A-level with girls, compared with the 6th most popular for boys. The Institute of Physics commissioned a review to try and understand the causes of this problem. Drawing on this review a teachers’ guide and two videos were produced to help teachers to find ways of encouraging more girls to study physics[34].

We would like to see a NSA for Wales draw on the research that has already been undertaken and tailor the solutions for Wales.

Even though we welcome many of the points in the Written Statement by Lesley Griffiths, Deputy Minister for Science, Innovation and Skills we are concerned that the NSA does not reflect what we believe a science academy should look like.

We believe that the NSA should be the following:

- have the respect of the whole science community
- not be affiliated or linked to any one organisation (it should be seen to be a pan-Wales independent organisation)
- have been discussed in public with involvement from the CSA and comparisons drawn to other Science Academies in other nations (e.g., Royal Society of Edinburgh[35])
- would be a body that would have an overarching view (along with the office of the CSA) of the issues facing STEM: for example, the supply of STEM-literate graduates in Wales, funding differences, etc.
- The NSA should act as a source of best practice in all remits. In education it could look at the evidence base and translate educational research into the classroom. For example, Girls in Physics is a resource that should be considered by each school in Wales.

[34] Girls in Physics
www.iop.org/education/teacher/support/girls_physics/page_41593.html

[35] The Royal Society of Edinburgh
www.rse.org.uk/

### A Science Policy for Wales 2006

This was a welcome document in that it highlighted the importance of Science within Government.

We would like to see a more specific action plan by the Welsh Assembly Government. For example the Science Policy states that in relation to teachers “we will strive to achieve a higher percentage who are science and mathematics specialists”. We fully support the aspiration but we would welcome an action plan (short-, medium- and long-term) on how to increase the number of specialist teachers, what would be defined as specialist teacher and what the actual numerical targets would be. The Welsh Assembly Government should set targets for the proportion of science classes taught to the 14–19 age range by subject specialists and collaborate with educational and scientific bodies to implement policies designed to meet the new targets.

## Conclusions

As has been highlighted throughout the document, many publications already exist which highlight issues within STEM and provide potential solutions for some of the problems. We recommend that a body looks at the evidence and statistics that already exist, and if gaps appear in the data, commission reports to complete the picture of STEM skills. Wales has two opportunities:

- We can take research and evidence developed elsewhere, either in the UK or abroad, look at whether the same issues appear and tailor best-practice developed elsewhere for Wales. This is a valid approach as in the current economic climate we do not have the time or money to repeat research undertaken elsewhere.
- As we are a small country we have a great opportunity in working together across all of the STEM disciplines to lead the way in increasing the flow of STEM-skilled persons into the workforce.

The Institute of Physics in Wales is a scientific membership organisation devoted to increasing the understanding and application of physics. It has over 1000 members, and it is part of the Institute of Physics.

The Institute of Physics in Wales aims to promote the role of physics in society, covering education, health, the environment, and technology. Its membership is wide-ranging and multidisciplinary, including the educational, industrial, medical, and general public sectors. The institute seeks common purpose with other organisations to promote science and science-based learning and to influence science policy. Special emphasis is placed on supporting physics teachers by promoting in our schools the value, joy and benefits of a knowledge of physics and its applications.

The Institute of Physics is a scientific charity devoted to increasing the practice, understanding and application of physics. It has a worldwide membership of around 40 000 and is a leading communicator of physics-related science to all audiences, from specialists through to government and the general public. Its publishing company, IOP Publishing, is a world leader in scientific publishing and the electronic dissemination of physics.

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