ESRC CENTRE ON
SKILLS, KNOWLEDGE
AND ORGANISATIONAL
PERFORMANCE

Technicians under the Microscope: The Training and Skills of University Laboratory and Engineering Workshop Technicians

SKOPE Research Paper No. 103 November 2011

Paul Lewis and Howard Gospel

King's College London

SKOPE

Editor's Foreword

SKOPE Publications

This series publishes the work of the members and associates of SKOPE. A formal editorial process ensures that standards of quality and objectivity are maintained.

Orders for publications should be addressed to the SKOPE Secretary, School of Social Sciences, Cardiff University, Glamorgan Building, King Edward VII Avenue, Cardiff CF10 3WT
Research papers can be downloaded from the website: www.skope.ox.ac.uk

ISSN 1466-1535

Abstract

This paper examines a neglected, but important, group of workers, namely technicians in university laboratories and engineering workshops. Using data from English universities, the main focus is on the qualifications, skills, recruitment, and training of technicians. Factors shaping employer decisions about recruitment and training are examined, in the context of broader human resource management arrangements and the development of technician registration.

1 Introduction

Technicians of various kinds make an important contribution to the organisations in which they work. Here we focus on laboratory and engineering workshop technicians in English universities, where the impact they make is on research and teaching. In turn, this contribution has a significant effect on the performance of the British economy (Sainsbury 2007: 35-37, 43-45; DBIS 2009a: 5-9).

Despite their important contribution, technicians have been little researched, both in the private and public sectors. There are a few notable US ethnographic studies which focus on the occupational identity of technicians, but little on their training (Barley and Bechky 1994; Barley 1996; Barley and Orr 1997; Toner *et al* 2010). Similarly, UK government policy documents on science and innovation have neglected the role of technicians (Sainsbury 2007: 95-116; DIUS 2009). This situation is despite suggestions that a shortage of technicians may be hampering the work of university science and engineering (The Royal Society 1998; Evidence Ltd 2004; THES 2008, 2009; Unite 2008). It is also despite other policy contexts, such as a stated government desire to increase apprentice numbers in the public sector and attempts to establish a technicians' registration scheme (Leitch 2006; Sandford Smith *et al* 2011).

This article seeks to remedy some gaps in the UK academic literature and in policy analysis by addressing three sets of questions. First, the article explores the different jobs university laboratory and engineering technicians perform and how they are organised and managed. Second, it is concerned with the qualifications and skills technicians actually possess and ideally require to perform their jobs. In doing so, it enquires into whether qualifications and skills should be at intermediate level or at graduate level and above. Third, the article is concerned with how science and engineering departments satisfy their need for suitably skilled technicians.

The structure of the remainder of the article is as follows. Section two sets out some of the key theoretical issues pertaining to employers' decisions about how to acquire the skilled labour they need. Section three outlines research methods. Section four considers the nature of the technician workforce in university laboratories and workshops. Section five is the main focus of the article and deals with qualifications and skills and with recruitment and training. In section six, there is discussion of factors shaping employer decisions, key aspects of the broader HRM context, and the idea of technician registration. In the conclusions, summary points, policy implications, and areas for further research are outlined.

2 Perspectives on Employers' Decisions about Skills and Training

There are a number of relevant dimensions which shape the employer's decision about the level of labour to employ and how to source that labour. First, there is a technological dimension which relates to the scientific discipline concerned and the related types of technician support. Thus, at one extreme, there may be some technician jobs where the tasks involved require sufficient knowledge of the relevant science that they can only be performed by someone with a degree. In another respect, it might be argued that historically the technologies supporting certain disciplines, especially areas of engineering and chemistry, had a large practice-based component of tacit or craft or trade-type skills. In turn, this suited traditional apprentice-type training. However, as the nature of the science has become more specialised and complex, so in turn there are pressures for support technologies to become more knowledge-based. In turn, this may produce pressures to recruit staff direct from universities (Gospel 1991; Brockmann *et al* 2011). Technology may operate in another way. Thus, if it is very much organisation-specific, this may push organisations towards internal training; if it is more generic, then it may push them more towards recruitment of staff with more general craft skills or scientific knowledge, respectively apprentices or graduates (Doeringer and Piore 1971). In the detailed cases below, we will see a number of significant changes in the technological support provided for university engineering and science.

Second, there is a labour market or human capital dimension. Organisations must choose between various alternatives for sourcing their skilled labour. We identify these as recruitment (hiring already trained staff), apprenticeship (a structured training programme for young people, combining on-the-job work and training with off-the-job learning), and upgrade (the training of employees, of all ages, employment tenures, and educational backgrounds, for more skilled jobs as they progress through a career). Consider then the labour market for university technicians. This is an imperfectly competitive market, for a variety of reasons: workers' skills are typically transferable in the sense that they are valuable to some, but not to all employers, not least because – as we shall see – workers' skills are often tailored to the specific requirements of the research groups for which they work; employers may well be uncertain about the skills possessed by potential recruits, either because the skills are uncertificated or certificated to standards that are not completely transparent; and the number of employers vying for such skills tends to be relatively small, so that employers have a degree of latitude in wage-setting. In these circumstances, employers have an incentive to bear some of the costs of training because, although workers who have been trained are paid a higher wage, the increase in their wage will be less than the rise in their marginal product, so that their employer will obtain a positive share of the returns from training. Equally, in these circumstances, recruitment is less attractive because employers must offer higher wages to attract new employees and to keep their current employees. In practice, employers will seek to minimise costs by using a combination of training and recruitment, with the contribution of training increasing as its marginal cost declines relative to that of recruitment. This implies that where there is a limited supply of skilled labour on the external labour market, firms will train rather than recruit and *vice versa* (Katz and Ziderman 1990; Stevens 1994: 537-41, 1999; Ryan, Lewis and Gospel 2006).

There is then the further question as to the choice within training, between apprenticeship and upgrade training. Employers will prefer upgrade training, with its just-in-time element and its emphasis on organisation-specific needs. In addition, upgrade training may be more likely to support the human resource practices of the organisation, given that it is organised informally for existing employees, often without external certification and without the external involvement typical in apprenticeship arrangements. The investment may therefore be less risky than apprenticeship and result in lower labour turnover. However, employers will prefer apprenticeship where skill requirements are high and the external supply of skilled labour is limited. Apprenticeship also allows for more initial screening and may also provide a broader platform of knowledge and skills on which later development can be built. Attempts may be made, under apprenticeship, to avoid higher labour turnover by making it more organisation-specific and trying to incorporate apprentice-trained labour by the use of sophisticated human resource practices. This having been said, we concede that, in practice, recruitment, apprenticeship and upgrade may not be alternatives and may well be combined. Just what combinations occur in specific universities and departments is the empirical question at the core of this paper.

Third, in discussing employer decisions, there is an institutional dimension which must be considered. Here we refer to two sets of institutions, one within and the other outside the organisation. Within the organisation, human resource management (HRM) practices may shape the decision as to whether to recruit or train. The so-called 'fit' between such practices and training may be loose in the sense that job tenure, promotions, and pay may not be related to training. In these circumstances, if employers train, they may lose staff, and this in turn will lead to a reduction in training and an increase in recruitment. As the fit between training and other HR practices becomes tighter, so the benefits of training can be expected to accrue more to the employer who provides it than to its competitors, and the use of training relative to recruitment to increase. In the terminology of HRM, to be effective, training needs to be 'bundled' with a variety of complementary practices (Lepak and Snell 1999; Guest *et al* 2003; Boxall and Macky 2009). Where this integration occurs, the preference may be more for upgrade training over apprenticeship since, as stated, the former may also be cheaper and less risky. If the employer does resort to apprenticeship-type training, then once again this will have to be integrated into HRM if it is to be effective.

Outside the organisation, there are various institutions which may shape skills and training. These include *inter alia* the state, the education system, trade unions and professional associations. Here we refer to one significant one which has recently been suggested for technicians, *viz* occupational regulation via workforce registration. As we will see in section six, there is at present some discussion of the registration of the technician labour force. This we deal with in more detail below. However, here we simply state that there is some evidence that occupational regulation, in the form of licensing, certification and registration, may shape labour market outcomes, such as skill supply and wage levels (Kleiner 2006). There is also some evidence that it can affect employer decisions about the types of labour to employ and whether to train (UKCES 2011).

3 Research Methods and Data Sources

Given a lack of a relevant data set of university employers and their technicians, we rely on various sources. First of all, we use secondary sources, including government and sector reports, Higher Education Funding Council for England (HEFCE) material and data from the Higher Education Statistics Agency. We also carried out a series of 31 interviews with sector level organisations, such as government departments, funding bodies, sector skills councils, learned societies and technicians' organisations. Wherever possible, documentation was collected in the form of both published and unpublished materials.

Second, we used a case study approach which allowed us to explore employers and technicians in some detail. The goal was to select what were, as far as possible, closely matched case studies that were similar in most ways but which differed in particular attributes of interest (e.g. same discipline, same type of university, but different local labour market conditions) and to use comparisons between them to highlight key influences on the skills and training strategies adopted by universities in the case of their technicians. So, for example, cases were selected: to include both engineering and biological sciences (on the basis that the former might be more likely to recruit workers from local industry, while the latter might rely on national markets for graduates); to include both pre- and post-1992 universities (because of the potentially different duties and therefore skills required of technicians in those universities); and also to include different locations (and, therefore, potentially different local labour market conditions). In all, case studies were conducted in 45 departments covering four disciplines, namely engineering, physics, chemistry and biological sciences (including biochemistry, pharmacology, plant sciences and zoology and hereinafter referred to as biosciences). The cases were drawn from 18 different universities, 14 pre-1992 and 4 post-1992, covering London and the South East, the Midlands, the North-West and the North of England.

Information was collected via semi-structured interviews with academics, technical services managers and technicians, using a schedule piloted in the early cases. A summary of the cases is provided in Tables 1 and 2. A total of 96 interviews were conducted in the case study organisations. A majority were face-to-face, with seven taking place by telephone. Interviews averaged 90 minutes in length. Notes were written up and responses coded to assist the discovery of patterns. Where gaps were revealed, these were filled by telephone or email follow-ups. Primary and secondary documentation was also collected from the departments where available.

Table 1: Number of different kinds of case study departments and interviews

	Number of pre-1992 cases	Number of post-1992 cases	Total number of interviews	Number of academics interviewed	Number of technicians / technical services managers interviewed[b]
Biological sciences	9	4	28	11	18
Chemistry	10	1	17	8	14
Engineering	8	4	26	14	20
Physics[a]	8	1	13	7	13

Notes:
a: In addition, there were two interviews, involving one academic and 5 technicians/technical services managers at the two non-university research laboratories
b: 10 interviews were also conducted with human resource and development personnel from 5 universities

Table 2: Summary of the case study departments (depts)

Mean number of: / Discipline	Academics	Postdocs	Under graduates	PhD	Technicians	Technical Officers	Average ratio of academics to technicians
Biological sciences (13 depts)	52	67	552	92	37	3	1.3 (pre-1992)[b] 1.9 (post 1992)
Chemistry (11 depts)	42	60	470	145	20	5	1.8 (pre-1992) 1.4 (post-1992)
Engineering (12 depts)	133	121	1340	367	53	4	2.7 (pre-1992) 2.0 (post-1992)
Physics (9 depts)	57	87	364	150	32	2	2.8 (pre-1992) 1.4 (post-1992)

Notes:
a: In calculating the ratios of technicians to academics, (i) 'technicians' includes 'technical officers' and (ii) departments are weighted according to the number of academics they contain. The unweighted averages were: bioscience - 1.5; chemistry – 1.8; engineering – 2.3; and physics – 3.3.
b: Given that technicians in post-1992 universities tend to concentrate largely on teaching rather than research, ratios for pre- and post-1992 universities are presented separately

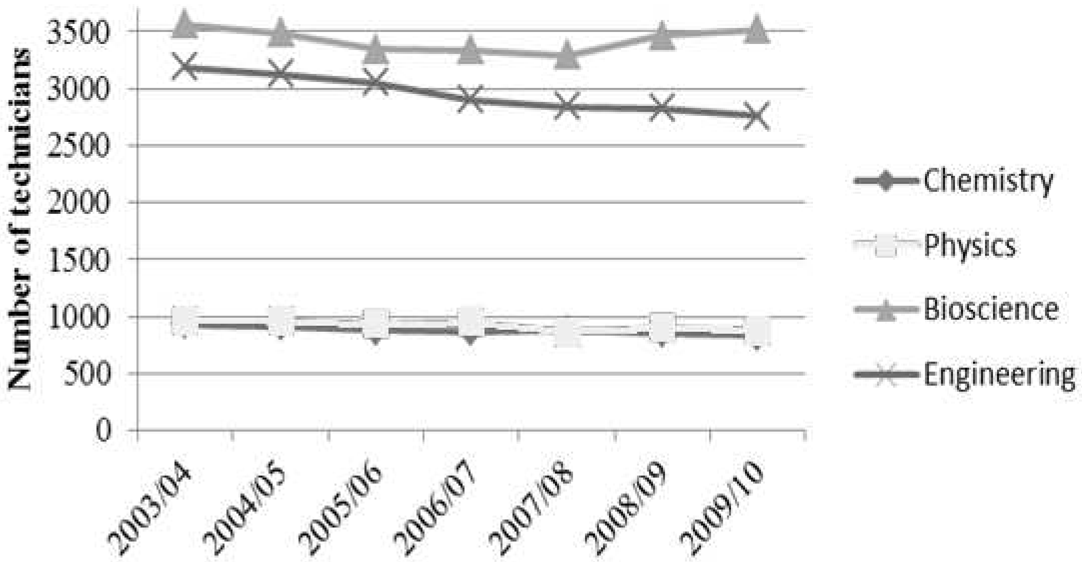
4 The Technician Workforce

4.1 Technicians – definition and numbers

We define a technician as someone who is skilled in the use of particular instruments, equipment, techniques and procedures aimed to solve practical problems. This often requires considerable dexterity, ingenuity and creativity. It also requires specialised training and significant experience to perform the job effectively (Barley and Orr 1997: 12-15; OECD 2002: 92-94; Technician Council 2011). Viewed in another way, technicians can be seen to work at the interface between the symbolic world of academic scientists and engineers and the material world, serving as the bridge between the two. In doing so, technicians make an extremely important contribution to the work of the scientists and engineers whom they support (Barley and Bechky 1994: 88-92, 115-16; Whalley and Barley 1997: 47-50; Lewis and Gospel 2011: 16-20).

In university science and engineering departments, a first group of technicians provide practical support with specific research projects. A second group provides more general support for research and teaching by maintaining the technical infrastructure of departments. A third group supports the teaching of students. These types will be elaborated on below.

Figure 1: Total number of technicians in bioscience, chemistry, engineering and physics in UK higher education, 2003/04 – 2009/10[a]



a: Source: HESA Staff Record 2003/04-2009/10. The figures refer to the full time equivalent number of laboratory, engineering workshop, building, ICT and medical (including nursing) (SOC Code 3A) technicians in each of the following cost centres: bioscience, chemistry, physics, engineering (including general engineering, chemical engineering, mineral, metallurgy and materials engineering, civil engineering, electrical, electronics and computer engineering and mechanical, aero and production engineering. Comparable data are unavailable before 2003/04.

Figure 1 presents UK data for technicians in the four disciplines over the period 2003/04 to 2009/10. It will be seen that we are concerned with a relatively small workforce. Overall, the largest number of technicians are to be found in the biosciences and engineering, with chemistry and physics quite some way behind.

Over that period, the absolute number of technicians has declined by 14 per cent in engineering, by 11 per cent in chemistry and by 8 per cent in physics, with the biosciences relatively stable (displaying a decline of just 1 per cent). Using the same data and calculating the ratio of academics to technicians, this increased in all four disciplines – from around 2.9 to 3.4 in biosciences, 3.6 to 4.4 in chemistry, 3.7 to 4.8 in physics and 4.3 to 5.2 in engineering.

In our case studies, there was also said to be a reduction in numbers, over the past decade and more, both absolute and also relative to the number of academics and students supported. Most interviewees stated that this had not yet led to significant difficulties in providing support for research and teaching. However, four bioscience departments said that teaching support had deteriorated and five of the departments in post-1992 universities were concerned that they did not have the support to meet increasingly demanding targets for research and consultancy.

4.2 Types of technicians and their work

As already suggested, there are a number of different types of technicians in laboratories and workshops. Here we outline the main types and work they do, while cautioning that in practice roles sometimes overlap.

First, 'stores' or 'infrastructure' technicians provide general support for research and teaching activities by warehousing, maintaining equipment and preparing samples and chemicals. These are to be found in most departments. Second, 'mechanical and electronic workshop' technicians are involved in the design, construction and maintenance of equipment used in research and teaching, mainly in engineering and physics. Here, they work closely with academics, with the skills, experience and knowledge of the two groups complementing one another in what one academic referred to as 'professional collaboration'. In particular, academics often provide technicians with no more than a rough sketch of the kind of instrument or apparatus required to solve the technical problems that arise in the course of their research. It is then up to the technicians to draw on their knowledge and practical expertise of electronics and mechanical engineering – their knowledge of the properties of different kinds of material and their understanding of what particular tools can be used to achieve – along with their general problem-solving skills in order to design and build the requisite instrument, electronic component, or experimental rig. As one physics interviewee stated, ‘technicians are a repository of deep, long-standing knowledge of what works and what doesn’t work’ (cf. Barley and Bechky 1994: 91, 116-120; Barley and Orr 1997: 44-45, 51-52).

A third group of technicians, sometimes referred to as ‘analytical facilities’ technicians, provide research support for a number of different groups within a department. Their contribution centres on the operation of particular instruments and experimental techniques, such as NMR spectroscopy, mass spectrometry and X-ray crystallography. Over the years, such technicians have often developed considerable practical expertise in the use of such instruments and techniques, on the basis of which they are able to provide scientists with important advice about how to prepare their samples for analysis, about how to ‘optimise’ the instruments so that they are appropriately set up for the piece of analysis being undertaken and also about how to interpret the data that are generated. As one technical services manager described the work:

> they know the instrument inside out, they will know its foibles, how to push it to its maximum performance… That comes through experience, not formal training.

These technicians are to be found in most departments.

A fourth group, sometimes referred to as ‘research laboratory’ technicians, provide support for specific research groups, by preparing equipment and materials, conducting experiments and analysing data. Such technicians are most numerous in chemistry and the biological sciences.

Fifth, in every department, across all four disciplines, there are ‘teaching’ technicians who support teaching by preparing materials and equipment and overseeing their use. In engineering departments, in all the universities visited, some of the technicians were actually involved in teaching students, through demonstrating how to use particular instruments and techniques or by assisting with projects. Similarly, in physics, chemistry and biosciences in all post-1992 universities, technicians were also actively involved in teaching students. However, there are constraints on this involvement, imposed by both the limited theoretical knowledge possessed by many technicians, by rising staff student ratios and by the increasing demands of research and consultancy work. It would not therefore seem to be the case, as some have suggested (PA Consulting 2010: 29), that technicians will become more and more deeply involved in teaching, unless their educational and training backgrounds change.

Finally, intermediate between academics and technicians, there exist ‘technical’ or ‘scientific officers’. These are found exclusively in pre-1992 universities, especially in engineering and chemistry. Though performing various roles, these tend to specialise in particular instruments and techniques, such as NMR spectroscopy and X-ray crystallography. Such staff are more likely to be involved in design and management of research projects and are the technicians who are most likely to be listed as authors of scientific papers. For the other technicians referred to above, we will discuss their training and qualifications below, but here we briefly deal with technical officers. In terms of skills and knowledge, they are more likely to have a combination of the technical and the academic (BSc, MSc or many with a PhD). Older technical officers, who may have come through the vocational route of apprenticeship, are often likely to have acquired an academic qualification *en route* through their careers. More recently, most technical officers have tended to follow an academic rather than a vocational path.

We make a number of brief final comments. First, there may have been some small invasion of technician work by PhD students and junior researchers. However, this was not a point stressed by informants and there are practical and time constraints on this. Second, in an attempt to exploit economies of scale, there has been some tendency towards the pooling and centralisation of generic types of technician support (e.g. autoclaving, washing glassware, etc) in department or even faculty-level workshops. This has been taken furthest with the creation of shared services operations in some post-1992 universities. However, this was not popular with academics and even less so with technicians. In practice, centralising tendencies were said to be often subverted for good practical reasons. Third, there was some increase in outsourcing of work, especially in the biological sciences and in the provision of teaching support, where more use is now made of pre-prepared and disposable experimental kits. However, in the case of research support in particular, the fact that there is often uncertainty at the outset of projects about the kind of support that is required and the type of experimental apparatus or instrument that will have to be built raises the costs of external contracting, militating against outsourcing and encouraging departments to keep such work in-house. Overall, neither changes in skill mix nor reorganisation would seem to be altering the need for technicians or downgrading their work.

4.3 Employment contracts, tenure and the age of technicians

The majority of technicians were on open-ended, rather than fixed-term, contracts. This varied from a low of around 80 per cent in bioscience to a high of 90 per cent in physics. However, some of those on open-ended contracts were dependent in part for financing on external research grants. In sum and despite pressures on universities, there seems to be little by way of numerical flexibilisation of this part of the university labour force.

Labour turnover was universally reported to be very low, with many departments reporting turnover of less than five per cent and almost all with less than 10 per cent (see also HEFCE 2010: 80). However, it was stated that this could be a mixed blessing. On the one hand, stability ensures that reserves of experience are maintained. Given that much of the knowledge is tacit, *viz* practical knowledge of how to do things, this is important. As one interview said: 'technicians provide much of the "institutional knowledge" in departments, by saying "Don't try that, it didn't work, try this"' (cf. Royal Society 1998: 9-10; Evidence Ltd 2004: 52). In theory, this stability should also encourage training. On the other hand, representatives of bioscience and engineering departments in particular, pointed out that skills may cease to be relevant. This is particularly the case where staff are unable or unwilling to be retrained or where departments fail to provide up-date training.

This failure to keep up with technological change was mentioned by representatives of some engineering departments who lamented the fact that older technicians lacked mechatronic skills (i.e. the ability to integrate mechanics and electronics). The problem also appears to be acute in the biosciences, where the rapid pace of change – in particular the automation of experimental procedures such as DNA sequencing – and the introduction of new analytical and data handling techniques has left some technicians with skills peripheral to departmental needs (cf. Barley and Bechky 1994: 120-21). Early retirement and voluntary severance schemes in universities have only partially helped to alleviate this problem.

The average age of technicians in engineering, physics and chemistry is around 50 years. Put another way, roughly half the technicians in these departments are due to retire within the next 15 years. Matters are rather different in biosciences, where the average age is around 40 and where around 40-45 per cent are likely to retire within the next 15 years. As we will see, in biosciences this reflects a tendency in recent years to recruit relatively young graduates to technician posts (cf HESA Staff Records, cited in Lewis and Gospel 2011; 27).

Age profiles of the kind found in engineering, physics and chemistry are the cause of much concern, voiced both by interviewees and also by commentators (Evidence Ltd 2004: 14-15; THES 2008, 2009). Undoubtedly a succession planning problem is arising which must be addressed if technical support is to be assured. Of course, quite how serious the problem is depends on how easily suitable replacements for retirees can be found. This leads to the key set of issues at the core of this article: the kind of qualifications and skills technicians currently have; the kinds which departments require; and how skills are to be obtained in the future, whether by recruitment or training and what kind of training.

5 Qualifications, Skills and Training

5.1 Origins of technicians

Our interviewees were able to estimate the proportion of technicians who came straight to the department from school and were developed in-house via some kind of apprenticeship and the proportion who were recruited from the external labour market, having been trained and worked elsewhere. A surprisingly high proportion had come from school and been trained in-house. Thus, all 12 of the engineering departments estimated that around 30 per cent were internally grown. In seven of the nine physics departments, this was only slightly lower. The picture is similar for bioscience and chemistry, with around 30 per cent in the former and slightly lower in the latter being internally developed.

Those developed internally now tended to be older and to have done a traditional university workshop or laboratory apprenticeship. The latter typically involved on-the-job training, with rotation around workshops and laboratories and off-the-job training via day release at a local college (leading to vocational qualifications such as City & Guilds or an HNC). However, most of these schemes were discontinued in the 1990s, primarily because the need to reduce the technician workforce at the time militated against taking on apprentices (see also Royal Society

1998: 6 and Evidence Ltd 2004: 14). However, as we shall see below, recent years have seen a revival of interest in apprenticeship training, at least in engineering and physics.

Turning to external recruitment, it is unsurprising that this constitutes the main source of labour, as it does in most organisations. In engineering and physics, the main outside source was industry. However, some of these recruits (an unknown minority) had initially been trained in universities and occasionally had even returned to their old departments. In the biosciences, the sources of recruits were slightly more varied. While industry was a prominent source, bioscience departments also drew more on recruits from other university departments (accounting for 20-30 per cent of the current workforce in some cases). In six out of 10 of the bioscience departments which were able to provide data, it was estimated that 20-30 per cent were recent graduates, having been recruited soon after completing an undergraduate degree.

5.2 The profile of present qualifications

Table 3 provides a broad summary of the qualifications possessed by the different types of technicians in pre-1992 universities. We comment on post-1992 universities as relevant.

Table 3: Qualifications typically associated with particular technician roles in pre-1992 universities

	Engineering	Physics	Biosciences	Chemistry
General support	Vocational	Vocational	Vocational	Vocational
Workshop	Vocational	Vocational	Vocational	Vocational
Analytical facilities	Vocational	Vocational	Vocational/BSc	Vocational/BSc
Research	Vocational	Vocational	Vocational/BSc	Vocational/BSc
Teaching	Vocational	Vocational	GCSEs/ vocational/BSc	GCSEs/ vocational/BSc
Technical officer	BSc/PhD	BSc/PhD	BSc/PhD	BSc/PhD

It will be seen that the qualifications held by general support, mechanical and electronics workshop and facilities technicians and also technical officers, tends to be similar across all disciplines. General support technicians typically have at most relatively low-level vocational qualifications, such as BTECs and ONCs. The majority of mechanical and workshop technicians, in both pre- and post-1992 universities, have vocational qualifications in electronics and mechanical engineering, usually City & Guilds or HNCs/HNDs, with a very small minority (typically less than 10 per cent) having a BSc. Analytical facilities technicians in engineering and physics tend to have vocational qualifications, while in biosciences and chemistry some have an undergraduate degree.

In the case of research laboratory technicians, most are vocationally qualified. Exceptions can be found in some physics departments, where the nature of the work undertaken by electronics technicians requires a degree and also in some engineering departments that carry out interdisciplinary work in bioengineering or chemical engineering, where technicians who have at least a BSc in the relevant science are employed to help run the research laboratories in question and to provide subject-specific scientific input into the design of experiments and the analysis of data. In biosciences and chemistry, while older research technicians have vocational qualifications, younger technicians tend to have BScs. This tendency was attributed both to technological change and to differences in the availability of workers with different educational backgrounds. The premium is increasingly on technicians who can help with the design of experiments and analyse the data produced. Since these skills are most likely to be acquired via a degree, rather than vocational training, it is unsurprising that bioscience and chemistry technicians are increasingly graduates. Graduates were also said to have a better grasp of scientific principles underlying much research and to be able to operate with less supervision. Many interviewees in bioscience also argued that the rapid pace of technological change in their area made it especially desirable to recruit graduates for research support. A majority of the pre-1992 bioscience departments concluded that a first degree has become a prerequisite for the research technician role.

In the case of teaching technicians, in pre-1992 universities, qualifications depended very much on the degree of involvement in teaching: those who supported teaching had at most a vocational qualification; those who were more actively involved tended to be qualified at least to vocational level and some, in biosciences and chemistry, had either an HNC and considerable experience or possessed undergraduate degrees. In the post-1992 universities, where the teaching role is more predominant, most of the technicians in engineering and physics departments had vocational qualifications, with the exception of one engineering department where most of the technicians had an undergraduate degree. In the post-1992 universities, at least two thirds of the teaching technicians in biosciences had a degree, with many having an MSc or PhD.

We were concerned to ascertain whether academics and technical managers believed that there was a good match in skills between what was actually current and what was ideally desired for their departments' needs. Such a gap in the skills profile could take the form of under-qualification or over-qualification. In practice, most interviewees felt there was a satisfactory match; however, there were some exceptions to this picture.

In terms of under-qualification, around half the engineering departments and some of the physics departments, said they wanted more technicians with mechatronic skills. Other engineering departments said they would like to have more technicians with more 3-D CAM-CAD knowledge. More generally, engineering departments reported that they would like to have more technicians who are multi-skilled and able to respond to situations with greater flexibility. In biosciences some interviewees indicated that the skills of some of their older technicians were no longer relevant to the work they were supposed to be doing. In terms of over-qualification, interviewees from biosciences from the post-1992 universities said that technicians with an MSc or PhD, which in two cases amounted to almost half of the workforce, are overqualified for their roles. As a result, departments under-utilise their skills.

We now move onto the routes which departments are taking to address the workforce planning and resourcing issues confronting them. We consider first the role of recruitment and then of training, both initial and on-going training.

5.3 Recruitment versus training?

5.3.1 Recruitment

It was stated above that recruitment has been the main method whereby technicians have been obtained during the past 15-20 years. It was also suggested that there is currently a contrast between bioscience and chemistry departments, which easily recruit a large number of graduates as technicians and engineering and physics departments, which struggle to recruit the kind of workers they require.

Interviewees from all 13 of the bioscience and nine out of 11 of the chemistry departments said they receive large numbers of applicants for technician posts (with ratios of 50 or even 100 applicants per place often being cited). This in turn reflects two factors: the large number of relevant graduates who have been produced by UK universities; and the reduction in employment in pharmaceutical and chemical companies. Several interviewees remarked that even advertisements for low level teaching technician posts attract interest, not only from large numbers of graduates but also from those with advanced degrees. Of course, not all the graduate applicants are appointable. Some lack the practical skills to fill a research or analytical facilities role. Also, young graduates and those with advanced degrees may fail to appreciate that they play a subordinate role in research and that the teaching support role can be mundane. Nevertheless, even when unsuitable candidates are excluded, bioscience and chemistry departments are usually left with many strong candidates from which to choose.

Recruits of all kinds need to be inducted and may also have to receive some additional training to equip them with some of the more specialised skills in their new departments. Most of this training is informal and on-the-job and reflects the fact that many of the techniques used in research laboratories are relatively new and may not yet have been adopted by industrial laboratories or external training programmes. The same is often true in engineering and physics workshops where technicians may be required to work with new materials and to greater tolerances than is customary.

The abundance of appropriate labour means that bioscience and chemistry departments, when considering succession planning and workforce renewal, are able to rely on recruitment from the external labour market. One consequence and one exception to this should be noted. First, the consequence is that only one bioscience and no chemistry department among our cases currently runs an apprenticeship programme. Second, the significant exception is that the only kind of technician which chemistry departments struggle to find are those who work with mechanical and electronic equipment.

This brings us back to engineering and physics departments. A majority of these, in all parts of the country visited for this study, said they found it difficult to recruit technicians from the external labour market. In the words of one interview: ‘It’s not easy, and it’s getting worse… You have to be lucky to get a good one’. Two reasons were given for this. First, the salary paid by universities, which is said to be low relative to that in industry, makes it hard to attract younger technicians in particular. Second, the long-term decline of companies which traditionally trained technician-type staff and the scaling back of training programmes in those which survive has led to a reduction of the pool from which experienced technicians can be drawn. According to one technical services manager, 'The well's run dry' (see also Royal Society 1998: 6).

5.3.2 Apprenticeship training

It is for this reason, coupled with an ageing workforce, that there has recently been a revival of apprenticeship training by engineering and physics departments. Six of the 12 engineering and three of the nine physics departments have either recently begun, or are about to begin, apprenticeship schemes for technicians. Two other engineering departments and one other physics department, are formally considering such a scheme.

Two reasons for this renewed interest in engineering and physics have already been mentioned – an ageing workforce and the difficulty of obtaining suitably qualified skills on the external labour market. As one technical service manager stated: 'We need to grow our own; otherwise we'll have a skills shortage'. A further reason for these developments is that apprenticeship is seen as a way for departments to update workforce skills. In particular, this is the case if apprentices take a mix of units, say in mechanical and electronic engineering, thereby acquiring the mechatronic skills on which many departments now set great store.

Briefly, we describe the apprenticeship arrangements which are in place. All nine departments of engineering and physics and the non-university research laboratory have adopted similar frameworks. In every case, apprentices have been recruited under the auspices of the government's Advanced Apprenticeship programme. All nine departments have delegated formal responsibility for the running of the scheme to external training providers - seven to local colleges, one a private training provider, and one a group training association. However, in some cases departments felt they had to work hard to ensure that colleges deliver the quality of support required. In all cases, the external training provider holds the contract with the Skills Funding Agency. In this way, government funding covers the fees for college courses and the cost of assessing the National Vocational Qualification (NVQ) part of the framework. This leaves the department having to pay the apprentice wages, said to be around £12,000 - £13,000 per annum.

The departments typically look for young people, aged 16-20, with four to five GCSEs at A-C grades, with English and a science at C and maths at B. The quality of applicants was thought to be mixed. While some said they received good applicants to fill all the places on offer, two engineering departments struggled to do so. Once taken on, in all cases, the apprentices were given a fixed term contract of employment, coterminous with their apprenticeship. Apprentices typically start at NVQ2, working towards an NVQ3 and an ONC, often with a view of ultimately progressing to an HNC. The on-the-job training at work usually involves rotation through different workshops and laboratories, thereby developing breadth of experience and flexibility. The off-the-job training required for the ONC and HNC is via various combinations of block and day release. All the departments hoped and expected that apprentices will be kept on at the end of their training, subject to satisfactory performance.

However, it is important to note that the number of apprentices taken on is small, averaging just one or two per annum in each university. The ratio of apprentices to technicians is around three per cent in the physics and around five per cent in the engineering departments. The figures are expected to rise, if departments, most of which have only recently begun to take apprentices again, continue to do so and therefore ultimately have apprentices in all three or four years of their programmes.

Finally, we refer briefly to the 12 departments of engineering and physics which have not taken on apprentices. Of these, five have seriously considered doing so. However, despite acknowledging the potential of apprenticeship, they decided against for two reasons. First, two departments feared they would have to pay excessively high wages to retain newly qualified apprentices. These departments said they might well revisit their decision in the not-too-distant future. Second, some departments were concerned that current technicians were already stretched and would not have the time to provide on-the-job training. As one technical services manager put it: ‘We don’t have the time… and would have to take on an extra trainer to do it’.

Those engineering and physics departments which have not seriously considered taking on apprentices either still have a relatively young workforce or claim they can still find pools of labour in the external market. In other words, two of the main factors considered above (an ageing labour force and difficulty of recruiting externally) are not present. The absence of one or both of these factors also accounts to a large extent for the fact that only one of the 24 bioscience and chemistry departments is currently running an apprenticeship programme for general support, research laboratory, and facilities technicians. As one bioscience technical services manager pointed out: ‘Age is not a problem… Not all university departments have a succession problem’. In the words of another bioscience interviewee: ‘Given the ready supply of graduates, we don’t need apprentice laboratory technicians’.

5.3.3 On-going and upgrade training

Here we make a distinction between on-going and upgrade training. The former is more generic and refers to further training for existing staff; the latter is more specific in that it prepares staff for more skilled jobs as they move up some sort of career ladder and constitutes a more formal alternative to either recruitment or apprenticeship training.

Of course, most training is on-going for existing staff. Relatedly, it would appear that in an increasing number of departments the identification of training needs is gradually being formalised through the use of appraisal reviews. However, interviewees in a significant minority of departments indicated that this remains *ad hoc*, driven by short-term requirements of current research projects, rather than systematic appraisal of the longer-term needs of the individual and the department. Moreover, in a handful of departments, especially in engineering, appraisals have only recently been introduced. In others, while systems are formally in place, in practice they are not popular, especially among older technicians, and in practice appraisals are sometimes not carried out (see also HEaTED 2009; 11, 27).

On-going training is of two forms, certificated and uncertificated. Certificated training, leading to formal qualifications, is the least common. Nevertheless around a fifth of departments have sent non-apprentice technicians on certificated vocational courses, such as BTECs, HNCs, and HNDs. In addition, there are cases where departments would like to send staff on such courses, but this is constrained by the absence of courses in nearby colleges. This is true in the case of engineering and physics departments who have struggled to find colleges offering HNCs in electronics. It also applies to some bioscience and chemistry departments who would like to have some of their general support and teaching technicians take HNCs or BTECs in applied biology and chemistry. In the case of academic certification, a majority of the chemistry, engineering, and physics departments have also sponsored small number of technicians – typically just one or two - on BScs and three more have supported technicians on an MSc. Those technicians, especially technical officers, who have a PhD have often acquired this via research and publications undertaken whilst working as a technician.

In the case of uncertificated training, most of this involves upskilling on-the-job, with the assistance of other technicians or academics who are able and willing to give of their time. Another important source of uncertificated training is that supplied by equipment manufacturers. Training of this kind usually accompanies the purchase of new equipment and/or associated software, though it can also be obtained independently of the latter.

A number of obstacles to on-going training were mentioned. We have already referred to the perceived problems in terms of the supply of courses offered by colleges. Here we cite three others. First, it is often hard to release technicians, given demands on staff. In this respect, while some academic staff are very supportive of release for training, others were said to be less helpful. Second, there are significant and growing financial constraints, and technical services managers prefer, not surprisingly, to cut training budgets rather than cut staff. Third, a minority of – especially, older – technicians are often unenthusiastic about training. According to one manager, technicians have sometimes 'devalued themselves' by neglecting to update their skills, as a 'professional' approach would require. This is particularly the case where, as in engineering and in particular in biosciences, skill requirements have changed fast and old skills have become increasingly peripheral. Early retirement and voluntary severance have alleviated some of these problems, but not eliminated them altogether.

All in all, on-going training is vitally important for creating an optimal skills mix for departments. However, as organised in universities, it does not provide a systematic form of upgrade training which might constitute an alternative to the recruitment of staff or the training of apprentices.

6 Discussion

In this section we deal with three main questions. How do we explain the patterns of workforce planning and resourcing in the four disciplines across different universities and labour markets? How do skills and training strategies relate to broader HRM considerations? And is there a role for another kind of institution, namely the registration of the technician labour force? In turn, these questions relate back to the technological, market, and institutional dimensions of technician skills and training to which we referred in the introduction.

6.1 The dynamics of change

Technology, in the sense of the types of technical support for particular disciplines and sub-disciplines, shapes some decisions about the kind of labour to employ and how to source that labour. Thus, there is some technician work – such as electronics work in physics and cross-disciplinary work in bioengineering and chemical engineering – which we were told requires a degree. Also, though more difficult to determine, rapid change in the biosciences in recent years is a factor making it desirable for technicians to have a degree. In this case, we have referred above to the increasing demand for analytical and data handling skills, many of which are generic in nature and available on the graduate labour market. However, in other areas, such as the increasing demand for mechatronic skills in engineering and parts of chemistry, skills seem best acquired via apprenticeship training. The evidence we have collected unfortunately does not permit us to assess in any detail the relationship between the science, its supporting technology, and skills and training. However, it is clear that the changing demands of the technology used in research and teaching shapes, without uniquely determining, many skill and training decisions.

The labour market and human capital considerations also clearly shape skills and training decisions. Thus, we have seen a strong contrast between the biosciences and chemistry on the one hand and engineering and physics on the other. In the former, there is an abundant supply of skilled labour in the form of graduates, and departments have increasingly recruited such labour into technician jobs. In the latter, there is a scarcity of relevant labour and departments have had to look to internal training. Some of this has taken the form of on-going training which is often cost-effective. However, there are severe limitations to such training – there is an ageing labour force and in universities this sort of training tends not to be of the systematic up-grading kind. In these circumstances, engineering and physics departments have looked again to apprenticeship training, which is expensive and risky, but which may assure a supply of the requisite labour. However, this depends on a number of factors – how apprenticeship is structured, whether departments can hold onto their apprentice-trained labour, and whether external institutions support apprenticeship type training. In this context, we now turn to HRM and occupational regulation.

6.2 HRM issues around careers and status

Above we mentioned various aspects of HRM in these departments within their universities, some of which are supportive of training and some of which less so. Overall, one positive factor is that jobs are relatively secure and staff are on open-ended contracts. The downside of this was also mentioned in terms of skills being superseded. In addition, we described how more formal appraisal has increased, while noting also that in a significant minority of departments it remains *ad hoc* and in others is sometimes not carried out at all. We also suggested that finance is a major constraint on HRM and training of all kinds and is felt to have constrained pay levels of university technicians compared to those in the private sector. However, as an aside on pay, it should be noted that since 2005 technicians are on a single pay spine for all university posts, whether academic or other. It was generally felt that this had not disadvantaged technicians and in many instances has led to higher grades and higher pay.

There are two other HRM-type issues which are relevant, concerning careers and status. First, on careers, many technicians have reached the top of their current grade. As a result, the scope for increased pay is limited to a small number of discretionary points, but these are increasingly difficult to gain given the current financial situation. It is also limited to regrading, but this in turn is difficult to obtain unless the nature or range of tasks change significantly. Another way for these pressures to be eased is via promotion. However, a combination of the relatively flat organisational hierarchies that characterise university science and engineering departments, means that such departments have few senior technical positions, and long tenures, which implies that once occupied senior technical positions tend to remain filled by the same person for many years, implies that the scope for rapid promotion is usually very limited. In this regard, interviewees repeatedly used the same phrase, 'dead men's shoes' to describe this situation (see also Royal Society 1998: 7, 10; Evidence Ltd 2004: 4-5, 19). A further way to ease pressures might be for technicians to move on an inter-departmental or inter-university basis. Inter-departmental moves do happen, but are not common, being constrained by the range of skills acquired and mind-sets which some managers and academics dubbed 'parochial'. This relates to the point already mentioned that departments need to be more willing to offer, and technicians more willing to avail themselves of, opportunities for training in broader skills. Inter-university moves, and indeed moves out of the sector, do obviously take place. However, such moves are not likely to encourage training by individual departments.

Second, and related to careers, is the question of status. In many instances, HR managers, academics, and technical services managers have made changes to improve the status of technicians (e.g. by consulting them more, putting them on committees, giving them a higher profile in newsletters and other publications, and making awards for teaching technicians). However, the status gap between academics and senior university administrators on the one hand and technicians on the other is still great. At root, this reflects the fact that technicians' work stands at the interface between manual and mental labour. The danger is that, if the more knowledge-related aspects are not acknowledged, then technicians' work is associated only with physical effort and is therefore accorded low status (Shapin 1989; Barley and Bechky 1994: 116; Whalley and Barley 1997). While many academics appreciate the technicians' contribution, it remains the case that technicians often feel underappreciated. Moreover, in the world outside laboratories and workshops, because their role is to support and facilitate the work of another, more eminent occupation, which is also widely seen to exercise authority over them, their contribution to research tends to remain largely invisible, with the result that their standing is not commensurate with the true significance of their work (Shapin 1989; Barkley and Bechky 1994: 91). Similarly, within universities, some interviewees reported that very senior academics and administrators from outside the sciences betray a misunderstanding of the technician role by making comments to the effect that technicians do little more than set up equipment which is used by academics, making no significant contribution to research, and that therefore they need little training. As one technician put it, 'People don't know what we do.' This is sometimes said to lead in turn to a neglect of technical support by universities when strategic and HR plans are being devised. To quote the phrases used by a number of technical services managers, technicians are 'a forgotten workforce' who are all-too-often 'taken for granted' and treated 'as a bit of an afterthought' (see also Keefe and Potosky 1997: 77-81). Finally, in this respect it should be noted that, though there exist some professional associations for technicians and though union membership was once strong, these forms of employee voice were seldom mentioned as significant, in particular in relation to training.

In conclusion, although university HRM evidences areas of fit between HR and training, nevertheless HR practices do not powerfully promote training, of either an apprenticeship or upgrade type, over recruitment. This leads us to another possible means to encourage employers and technicians to avail themselves of training.

6.3 Registration

Here we define registration as a process whereby an agency, voluntary or statutory, registers the names and relevant details of individuals who work in a particular occupation. A certain level of skill or possession of certain qualifications is usually a prerequisite to join the register and, to remain on the register, there may be requirements for continuing personal development and on-going training. Those joining the register pay a fee and may have the right to a title of some kind (Kleiner 2006).

The Technician Council, established in 2010, has as one of its aims to consider the establishment of voluntary registration for technicians in engineering, science, ICT, and health care (DBIS 2009b: 18, 2010). Under its auspices, relevant professional bodies, such as the Science Council and the Engineering Council, are seeking to establish standards to judge eligibility for registration, along with requirements for continuing professional development. Those with the requisite skills, qualifications, and experience and who pay a fee, will be able to use a title after their name (such as, 'Registered Technician'). Schemes akin to this already exist. In practice, the Institute of Mechanical Engineers and the Institute of Electrical and Electronic Engineers already offer a technician grade of membership, though to date few technicians have registered (Sandford Smith *et al* 2011).

The objective of the Technician Council scheme is to provide an incentive for technicians to seek initial and further qualifications and training and thereby enhance their grading and promotion prospects with employers. It is also envisaged that it will better signal the skills of technicians, thereby increasing their appeal to a broader range of employers and further enhancing their wages and career prospects.

Ultimately, the further aim is to improve the status and esteem in which technicians are held, thereby persuading greater numbers of young people to pursue a career as a technician. Recent UK research provides some evidence that some of these beneficial consequences may flow (UKCES 2011).

In our case studies, academics, technical services managers and technicians displayed cautious optimism about registration. Points made were as follows. First, if registration and re-registration were organised in the right way, this could encourage a more rounded technical education and training for technicians. Second, any such scheme might have particular appeal to younger technicians who, as one interviewee put it, 'still have a career to forge'. Third, attaining registered status might be something which could figure in appraisal interviews, making them more real and more likely to result in positive training outcomes. Fourth, registration and the accompanying title might raise the status and esteem of technicians. Finally, registration could broaden the notion of a 'career', so that as to encompass not just the current employer, but employers in other universities and outside the university sector.

However, here lies a problem. As stated in the introduction, employers will be most likely to finance training if the increase in the value of what trained workers produce is greater than the increase in their wages over that same period. That condition is more likely to be satisfied if the increase in the workers' skills is not readily apparent to other employers. If the increase in the skills is apparent, then other employers will try to entice workers away from the training employer by offering higher wages, hence forcing the training employer either to raise wages to retain them or to lose them. Both of those alternatives will reduce the return the employer makes on the investment in training and will weaken the incentive to train. Because registration promises to increase the transparency of workers' skills, it may in fact cause employers to be less willing to pay for training and consequently trainees will have to pay more for their own training (Stevens 1999).

7 Conclusion

This article has used new empirical research to investigate an important, but neglected, group of workers who make a significant contribution to research and teaching in the UK. The skills and qualifications of the technician workforce vary by discipline, role and type of university and overall up to the present have been considered a decent match for departments' needs. However, the age profile of technicians in engineering, physics, and chemistry is giving rise to succession planning problems. In addition, there are also signs that changes in the kind of research that is being done and in the technology which is being used, are leading to changes in the skills which departments would like their technicians to possess, as exemplified by the increasing demand for analytical and data-handling skills (especially in bioscience and chemistry) and for mechatronic skills (especially in engineering and physics). We also found a stark contrast between bioscience and chemistry departments on the one hand and engineering and physics departments on the other. The former use the external labour market and have increasingly recruited graduates; the latter face a shortage of technicians and are pursuing more mixed strategies, including a renewed interest in apprenticeship training. These differences we explained by a combination of technological and market factors. Human resource practices play a mixed role in encouraging training. In this context, there has developed the idea of technician registration which potentially offers benefits, but faces real design challenges.

There are a number of policy implications. For employers, university managers, and academics, there must be doubts about the sustainability of the various skills strategies: the financial crisis militates against apprenticeships and against continuing training; the reliance on graduates may also prove unsustainable if the increase in student fees reduces the supply of graduates in these areas; meanwhile on-going and upgrade training is provided in a piecemeal fashion related more to short-term rather than long-term considerations. Employers need to think longer term about labour supply. More specifically, they need to organise to find time for training for established technicians and for apprentices where the latter are used or being considered. There may also be scope to explore some kinds of joint action and group training associations. For technicians themselves, it is more difficult to draw out policy implications, since for the most part they act very much as individuals. However, where possible, through their professional bodies, trade unions, and consultation arrangements within universities, they need to put the case for a more strategic approach to the training of technicians. If a well-designed registration scheme is put into place, then individual technicians will have seriously to consider registration. Finally, for government and other public bodies, there is a case for the dissemination of better information about apprenticeship and its encouragement where appropriate. Pursuant of a general policy interest in occupational registration at the present time (UKCES, 2011), government might wish to consider support for the ambitious registration scheme in the sector.

The present study has limitations, associated with the fact that most of our case study interviews were with managers and academics and in addition we were not able to observe the actual work of technicians. There is therefore scope for further research in this area. First, it would of course be useful to have some wider statistical data and it would be useful if agencies such as HEFCE and the Higher Education Statistical Agency could collect more data in this area. Ideally, this should include both employer and employee data. Second, to investigate some of the links, for example that between technology, the type of work, and skills training, it would be useful to have some detailed ethnographic studies focussing on skills and training. Third, it would be informative to look at other countries which have large and successful university science and engineering departments and to see how technical support is obtained and how technicians are educated and trained. Obvious candidates here would be the US, Germany, France and Japan. Fourth, within the UK, it would be instructive to consider these issues in the case of university IT and medical technicians and in the private sector, where candidates would be large firms in advanced manufacturing, chemicals and pharmaceuticals. Finally, we have referred briefly to developments with the registration of technicians; at the least, this is a situation which should be monitored.

References

Barley, S.R. (1996) ‘Technicians in the workplace: ethnographic studies evidence for bringing work into organization studies.’ *Administrative Science Quarterly*, 41: 404-41.

Barley, S.R. and Bechky, B. (1994) ‘In the backrooms of science: the work of technicians in science labs.’ *Work and Occupations*, 21: 85-126.

Barley, S.R. and Orr, J. (1997) ‘Introduction: the neglected workforce’, in S. Barley and J. Orr (eds.) *Between Craft and Science: Technical Work in US Settings*. Ithaca and London: Cornell University Press.

Boxall, P. and Macky, K. (2009) ‘Research and theory on high-performance work systems: progressing the high-involvement stream.’ *Human Resource Management Journal*, 19: 3-23.

Brockmann, M., Clarke, L. and Winch, C. (2011) *Knowledge, Skills, and Competence in the European Labour Market*. London: Routledge.

DBIS (2009a) *Skills for Growth: The National Skills Strategy*. Cm 7641. London: TSO.

DBIS (2010) 'New champion for skilled technicians.' Press release 6th April 2010. http://www.whitehallpages.net/news/archive/319441. Accessed 25th February 2011.

DIUS (2009) *The Demand for Science, Technology, Engineering and Mathematics (STEM) Skills*. London: Department for Innovation, Universities and Skills.

Doeringer, P. and Piore, M. (1971) *Internal Labour Markets and Manpower Analysis*. Cambridge, Mass.: DC Heath.

Evidence Ltd (2004) *Highly Skilled Technicians in Higher Education: A Report to HEFCE by Evidence Ltd*. Leeds: Evidence Ltd.

Guest, D., Michie, J., Sheehan, M. and Conway, N. (2003) 'A UK study of the relationship between human resource management and corporate performance.' *British Journal of Industrial Relations*, 41: 291–314.

Gospel, H. (1991) (ed.) *Industrial Training and Technological Innovation*. London: Routledge.

HEaTED (2009) *HEaTED Survey 2009: Full Report*. Available online at: http://www.heated.ac.uk/uploaded/survey_pages/HEaTEDSurveyFullReport.pdf Accessed 25th February 2011.

HEFCE (2010) 'The higher education workforce framework 2010. Main report.' Bristol: HEFCE. Available online at: http://www.hefce.ac.uk/pubs/hefce/2010/10_05a/10_05a.pdf . Accessed 3rd January 2011.

Higher Education Statistical Agency, Staff Records 2003/4 onwards.

Institute of Physics and Royal Society of Chemistry (2010) *Follow-up Study of the Finances of Chemistry and Physics Departments in the UK*. London and Cambridge: IoP and RSC.

Katz, E. and Ziderman, A. (1990) 'Investment in general training: the role of information and labour mobility'. *Economic Journal*, 100: 1147–1158.

Keefe, J. and D. Potosky (1997) 'Technical dissonance: conflicting portraits of technicians.' in S. Barley and J. Orr (eds.) *Between Craft and Science: Technical Work in US Settings*. Ithaca and London: Cornell University Press.

Kleiner, M. (2006) *Licensing Occupations: Ensuring Quality or Restricting Competition*. Kalamazoo: Upjohn Institute.

Lepak, D. and Snell, S. (1999) 'The human resource architecture: toward a theory of human capital allocation and development.' *Academy of Management Review*, 24: 31-48.

Leitch Review (2006) *Prosperity for all in the Global Economy – World Class Skills* (Final Report). London: HM Treasury.

Lewis, P. and Gospel, H. (2011) 'Technicians under the microscope: a study of the skills and training of university laboratory and engineering workshop technicians,' London: The Gatsby Foundation. Available online at:

http://www.kcl.ac.uk/sspp/departments/management/people/academic/lewisgatsbyreport.pdf

OECD (2002) *Frascati Manual: The Measurement of Scientific and Technological Activities: Proposed Standard for Surveys of Research and Experimental Development*. 6th edition. Paris: OECD.

PA Consulting (2010) *The Future Workforce for Higher Education: A Report to HEFCE by PA Consulting Group*. London: HEFCE. Available online at: http://www.hefce.ac.uk/pubs/rdreports/2010/rd03_10/rd03_10.pdf Accessed 23rd February 2011.

Royal Society (1998) *Technical and Research Support in the Modern Laboratory*. London: The Royal Society.

Ryan, P., Gospel, H. and Lewis, P. (2007) 'Large employers and apprenticeship training in the UK.' *British Journal of Industrial Relations*, 45: 127-53.

Sainsbury of Turville, Lord (2007) *The Race to the Top: A Review of Government's Science and Innovation Policies*. London: HM Treasury.

Sandford Smith, D., Lewis, P. and Gospel, H. (2011) 'Technician registration.' in *Technical Education for the 21st Century*. London: The Gatsby Foundation. Available online at: http://www.gatsby.org.uk/techedu.html Accessed 2nd April 2011.

Shapin, S. (1989) 'The invisible technician.' *American Scientist*, 77: 554-63.

Stevens, M. (1994) 'A theoretical model of on-the-job training with imperfect competition,' *Oxford Economic Papers*, 46: 537–562.

Stevens, M. (1999) 'Human capital theory and UK vocational training policy.' *Oxford Review of Economic Policy*, 15: 16-32.

Technician Council (2011) 'Presentation – The Technician Council.' London: The Technician Council.

THES (2008) 'Labs at risk from loss of expertise.' *Times Higher Education Supplement*, 4th January.

THES (2009) 'Labs face crisis due to shortage of technicians.' *Times Higher Education Supplement*, 16th April.

Toner, P., Turpin, T., Woolley, R. and Lloyd, C. (2010) 'The role and contribution of tradespeople and technicians in Australian research & development - an initial study.' University of Western Sydney: Centre for Industry and Innovation Studies.

Whalley, P. and Barley, S. (1997) 'Technical work in the division of labour: stalking the wily anomaly,' in S. Barley and J. Orr (eds.) *Between Craft and Science: Technical Work in US Settings*. Ithaca and London: Cornell University Press.

UKCES (United Kingdom Commission on Employment and Skills) (2011) *Final Report on Occupational Regulation*. London: UKCES.