GLOBELICS 2011 - 9th International Conference

Creativity, Innovation and Economic Development

15 - 17 November 2011

Intercontinental Hotel, Buenos Aires, Argentina

Sub-theme: Human resources, competence building and specialization pattern: how to build local capabilities in a global context.

Skilled trades and technical workers in R&D: Occupations, organisation & innovation

Authors

Tim Turpin (t.turpin@uws.edu.au)
Centre for Industry and Innovation Studies, University of Western Sydney, Australia

Phillip Toner (ph.toner@uws.edu.au)
Centre for Industry and Innovation Studies, University of Western Sydney, Australia

Richard Woolley (richarddwoolley@gmail.com; r.woolley@uws.edu.au)
CSIC-UPV INGENIO, Valencia, Spain
Centre for Industry and Innovation Studies, University of Western Sydney, Australia

Chris Lloyd
Wiyanga Pty Ltd, Australia

Skilled trades and technical workers in R&D: Occupations, organisation and innovation

Abstract

Human resource capacity for national innovation systems is generally focused on the availability of scientists and engineers. However, skilled technical occupations make up approximately one third of the workforce involved in R&D in OECD countries, yet little attention is paid to these occupations in analyses of the organisation and conduct of R&D. Given the outward migration of scientists and engineers from many developing countries development strategies might be better focused on maximising available innovation inputs from technical and trades skills. This paper describes aspects of an exploratory study undertaken in Australia with the key aim of developing better understanding of the role and contribution skilled trades and technical workers make in the diverse contexts of R&D. The study also investigated forms of work organisation and the influence of formalised routines and informal work practices on task and project performance. We found trades and technical workers were involved in a wide range of activities directly related to R&D. These activities composed five key roles: installing, calibrating and customizing instruments; design; linking R&D to production; health and safety regulation; and training. The contribution of trades and technical workers to R&D exceeded simple execution of plans or designs provided by scientists or engineers however. Key forms of craft knowledge were important to innovation in the conduct of projects and in their outputs. These included knowledge of the properties of materials, the importance of design for maintenance and the carriage of non-codified knowledge – particularly of as-built artefacts and of adaptation to technical change – from one project context to another. We conclude that trades and technical workers should be understood as providing far more than ‘support’ in R&D contexts. Rather, the appropriate integration and timely involvement of trade and technical occupations in project teams adds dimensions of skill, adaptation and learning to R&D that can have significant benefits for the conduct of knowledge intensive work and for efficiency in translating knowledge between R&D, quality control and production processes. This has significant implications for R&D project management and work organisation practices in developing economies.

INTRODUCTION

The role of technical and organisational innovation in productivity growth and competitive success is now widely recognised. There is also increasing recognition of the strong causal inter-relation between growth in the supply of higher levels of education, training and skills and increased demand for and supply of technical and organisational innovation. To date much of the research on skills and innovation, including that occurring within R&D sites, has been directed at higher level science and engineering qualifications. Moreover, there is little in the literature about the ways technical and trade skills contribute to innovation and technological development in developing economies. Public policy has also been directed primarily at increasing the quantity of higher degrees and interaction between publicly funded research and the end users of knowledge and technology (industry or government).

More recently there has also been increased recognition of the importance of vocationally trained *occupations*, especially trades and technicians, in incremental innovation in production across a wide range of industries through their role in diffusing and adapting new technologies (von Hippel 2005). Despite this recognition, there "is little systematic knowledge about the ways in which the organization of education and training influences the development, diffusion and use of innovations" (Edquist 2005: 185). In addition, there is a lack of empirical research focussing on the specific role and contribution vocationally trained occupations may make to R&D activity. In the Australian context, this represented a major gap in collective understanding of the innovation process given these occupations comprise around 46 per cent of the Australian business R&D workforce and 30 per cent of the total Australian R&D workforce (ABS 2007a; 2008b).[1] A similar proportion applies across the European Union (OECD 2006: Tables 27, 30).

The value of scientists and engineers for economic growth and competitiveness increases as western economic systems become more reliant on the knowledge-generating and value-

---

[1] Within the classification used across the OECD for R&D statistics, the *Frascati Manual* (2002), data is collected on three broad occupational groups within R&D, researchers, technicians and other supporting. 'Researchers are professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned... Technicians and equivalent staff are persons whose main tasks require technical knowledge and experience in one or more fields of engineering, physical and life sciences or social sciences and humanities. They participate in R&D by performing scientific and technical tasks involving the application of concepts and operational methods, normally under the supervision of researchers...Other supporting staff includes skilled and unskilled craftsmen, secretarial and clerical staff participating in R&D projects or directly associated with such projects (OECD 2002: 92-94).

adding capabilities of science and technology. A major difficulty for many countries in the South, however, has been that while they invest in training for scientific and engineering careers, the brightest of these skilled personnel are frequently attracted to further training and long-term employment opportunities in the industrially developed economies. As the struggle for skills acquisition continues transnational corporations are moving their research facilities around the globe to wherever scientific skills are most readily available. Newly industrialized economies such as Singapore and Taiwan offer highly attractive salaries and conditions to attract global scientific leaders (Turpin et al., 2008). An S&T brain drain has thus been argued to hamper technological progress for sustainable development, with the absorption of S&T 'talents' into older and newer industrial economies contributing to a pervasive shortage of scientific and technical skills in the countries of the South.

The study reported in this paper set out to investigate the role and contribution of trade and technical occupations in R&D. The research had two major goals: first, to provide a detailed account of the activities and functions of trade and technical occupations in R&D worksites; and second, to contribute to the formation of more precise research questions for future study of the topic. The analysis presented in this paper explores some of the implications of the Australian study for training and learning for innovation and development in developing countries. One of the key conclusions we draw is that understandings of human capital, skilled personnel and competence building need to enlarge the scope of occupations that are considered integral to innovation and enhanced capability, whether in established industries, growth sectors or emergent technology niches.

SKILLS, INNOVATION AND TECHNICAL OCCUPATIONS

Background assumptions[2]

There are a multiplicity of linkages between knowledge, skills, education and innovation that are relevant to social and economic development and which we assume to be important. However, as Bruland (2003) points out: " [a] strong connection between education and economic development has often been proposed, but the content, mechanisms, and outcomes of the link remain a matter of debate". Difficulties in quantifying the relation between skills, education, knowledge and innovation are commonplace as each of these variables can be

[2] This section is drawn from Toner (2011).

specified in many different ways, using a variety of proxy indicators. Quality differences in data collection also mean there are major difficulties in comparing these variables over time and across countries. Furthermore, changes in the level and mix of workforce skills are the result of many causes, of which technical change (or innovation) is only one. For example, changes in workforce skills arise from alterations in international trade, migration, shifts in domestic consumer tastes and movements in per capita income.

For our analysis we assume strong and cumulative interactions between knowledge, skills and innovation. As Kim (2002: 105) has pointed out: '[w]hen more skilled workers exist, the market for skill-complementary technologies is larger. More of these technologies will thus be invented and they will be complementary to skills promoting faster upgrading of the productivity of skilled workers…an increase in the supply of skills can generate skill-biased technical change'. Mechanisms that promote the self-reinforcing interaction between knowledge, skill and innovation include the following.

- Growth in the 'volume' of productive knowledge requires ever higher workforce skills to identify, assess and implement new knowledge to the needs of particular firms.
- More skilled workers have greater 'functional flexibility' at work as their greater stock of knowledge increases the rate at which they learn and develop higher order problem solving skills.
- Firms that invest in innovation also have a higher propensity and intensity of investment in workforce training than firms that do not innovate.
- An increase in the overall skill level of a population, such as a rise in numeracy, literacy and scientific understanding, permits an increase in the complexity, variety and technical sophistication of products and services consumed.
- Investment in education and work-related skills is cumulative, such that higher levels of education and higher level occupations are strongly associated with higher rates of participation in employer-funded training.
- Improvement in the quality of skills through education, training and experience, along with improvement in the quality of ICT and capital goods, underpins the complementarity between capital and labour that is revealed in the long-run increase in the capital-labour ratio. Additional capital per worker and more specialised and flexible equipment enhances the scope for product, service and process improvements.

Innovation involves a broad range of economic activities, workforce skills and occupations. Requisite skills are not restricted to scientific and engineering occupations but involve, for example, direct production workers, tradespersons, technicians and people in marketing, financial management and human resources. Complementarities between the diverse human capital embodied by scientific, engineering and technical workers have been associated with both radical and incremental innovation strategies (Herrmann & Peine 2011). The involvement of a very broad range of occupations is also due to the fact that incremental change in products, services, processes and organisational structures is the predominant form of innovation. Such change relies largely on learning by doing and learning by using, or workers reflecting critically on the tasks they undertake, the equipment and software they use in supplying a good or service and on the design of the products and services they make. Such reflection is likely to be accentuated in R&D work contexts. Workforce skills are a necessary but not sufficient condition for successful innovation. There is considerable evidence that the type of work organisation adopted by firms is a critical factor in encouraging or retarding the engagement of workers in various forms of workplace improvement. The type of work organisation is also a critical factor in determining firms' demand for higher-level skills and investment in training. Finally, demand for higher level workforce skills depends on the growth of technically progressive and adaptive firms and industries, which public policy can to some extent promote.

Technical work

The role of technicians and tradespeople in production and economic activity has been the subject of a modest level of research from a range of perspectives, notably recently in the varieties of capitalism literature (Crouch et al. 1999; Thelen 2004). In contrast, there is an almost total absence of literature on the specific topic of the role of tradespeople and technicians in the innovation process. There is even less literature specifically on the role of these occupations in innovation in R&D settings. This significant gap in the literature was a major motivation for our exploratory study in Australia.

Over the last two to three decades there has been growing academic and corporate interest in improving the performance of the R&D workforce. For example Shapira's (1995: 1) comparative study of 'R&D workers' in the U.S., Japan, Germany and Britain is a comprehensive analysis of those 'personnel engaged primarily in the development of and application of new products, technologies and knowledge'. Despite this the focus of the comparative study was exclusively on professional scientists and engineers and had little to say about technicians and tradespersons. Other studies have examined the technician workforce from the perspective of the sociology of work. A series of complementary studies of technical work in the U.S. labour market were undertaken by Barley and colleagues (Barley & Orr 1997). These examined occupational identity of technical workers, including the conflict with traditional professional associations over recognition and entry, career paths, relative wage movements, unionisation, and rates of employment growth and how this is governed by the increased rate of technology development (Barley 1996; Barley & Orr 1997). Barley and Orr (1997: 12) defined technical work has having four attributes '(a) the centrality of complex technology to the work, (b) the importance of contextual knowledge and skill, (c) the importance of theories or abstract representations of phenomena, and (d) the existence of a community of practice that serves as a distributed repository for knowledge of relevance to practitioners'.

Several important points can be drawn from the various studies carried out by Barley and colleagues. First, most technical work in the realm of production takes place at what Barley terms a 'material interface', where the "production system meets the vagaries of the material world" (1996: 418). The symbolic work of designs and specifications and the material manipulations of production processes will lack accuracy unless the symbolic and the material are linked. According to Barley (1996: 418), the "core of technicians' work lies in creating these linkages… technicians stood with one foot in the material world and the other in a world of representations". Maintaining these linkages requires technicians to be problem solvers. However, as we argue below the organisation of work in many R&D settings is not conducive for maximising such problem solving and other creative activities essential for the innovation process. An emergent hypothesis is therefore that the hierarchical workplace arrangements that exist in some developing countries may work against this *essential* process.

Technical roles across a variety of fields function in different ways as 'buffers' and/or as 'brokers' (Barley 1996: 421-22). The representations generated by buffers become inputs for the work of another occupation, usually one considered a profession. Science technicians, engineering technicians in R&D labs, radiological technologists, emergency medical technicians, and medical technologists are examples given by Barley (1996) of this sort. 'Brokers', on the other hand, are roles "primarily responsible for creating or maintaining the technical infrastructures that enabled other people to do their work" (1996: 422). These different functional roles are thus very likely to be embedded in quite distinct structures of work organization. Buffers both interact regularly with professionals and insulate them from problems at the material interface. Brokers draw on distributed networks, including virtual networks, to search for knowledge and possible solutions to emergent problems.

Technicians' knowledge is complex, nuanced and context dependent. Formal education and theoretical knowledge has significant limitations, as it tends to date due to rapid technical change. Rather, formal technical education was valued for teaching "a more disciplined approach to solving problems" (Barley 1996: 425). The most valued form of substantive knowledge came from on the job learning and problem solving activity: a "situated, rather than principled knowledge of materials, technologies, and techniques" (Barley 1996: 425). The subtleties of technicians' knowledge are thus built up in specific contexts, and via interactions with a wide range of different occupational groups, adding weight to Amin and Roberts (2007) critique of simplistic applications of the concept of 'communities of practice' to forms of work with a strong craft base.

Machines, instruments and prototypes are staples of many forms of technical work and often provide the site for negotiation for different parts of the work organisation structure (Bechky 2003, 2006). In this sense, machines and other devices operate as 'boundary objects' that provide a situated context for complex knowledge integration processes (Trompette & Vinck 2009), coordination arrangements and problem solving criteria. This insight appears directly relevant for R&D worksites. As those who have direct carriage of material devices and their transformation, technicians are repositories of knowledge that is not codified or known outside the practitioner group. Technicians are reflexively aware of the limitations of their own mastery and the distributed nature of contextual knowledge (Barley 1996). This knowledge is maintained and distributed through interaction, including through demonstration of methods or techniques (Bechky 2003, 2006) and through the sharing of 'war stories' (Orr 1996).

THE AUSTRALIAN R&D TECHNICAL AND TRADES WORKERS STUDY

The Australian study of skilled trades and technical workers in R&D was exploratory in nature. It was based on a sample of in-depth interviews with 103 persons working at public sector, private and 'hybrid' R&D sites. Respondents included trades and technical workers (n=71) research managers (n=27) and some human resource managers (n=5) (see Table 1).

Table 1: Number of interviews x occupation x sector

Sector	Trades & Technicians	Research Managers	Human Resource Managers	Total
Public	48	14	3	65
Private	16	11	1	28
Hybrid	7	2	1	10
Total	**71**	**27**	**5**	**103**

All of the public sector agencies were large (ranging from several hundred employees to a few thousand); the two hybrids had approximately 100 workers each and all of the private sector enterprises were large with a minimum of 100 employees across Australia, with the exception of the capital goods maker for wood products which was a micro-business.

The interviews sought data on a range of variables including:

- demography;
- qualifications and their relevance to R&D activity;
- work history, recruitment in to R&D and career paths;
- extent and nature of interaction with scientists and researchers;
- identifying the specific roles of scientists/researchers and trades and technicians in R&D and the contributions they may make to the R&D process;
- work organisation systems in the R&D workplace and how this mediates the role and contribution of trades and technicians to innovation;
- factors affecting labour supply and demand for trades and technicians in R&D;
- skill gaps and how these affect R&D activity;
- methods used by trades and technicians to maintain the currency of their skills and knowledge.

Primary data for the study was collected via face to face semi-structured interviews conducted at R&D worksites. Two interview instruments were developed, one for tradespeople and technicians and another for scientists, engineers (researchers). Human resource managers were interviewed about background recruitment, employment, organisational and industrial issues. Each interview took 60-90 minutes to complete.

A number of limitations with the data must be mentioned. First, the sample is subject to some degree of selection bias as it was not randomly selected. Enterprises and individual interviewees elected to participate in the study so that it is uncertain how representative the sample is of the wider population. Second, the sample is not stratified to reflect the composition of entities undertaking R&D in Australia. The researchers did establish broad targets for key variables such as industry sectors, firm size, geographic location and ownership based on the distribution of R&D activity across Australia according to ABS data. However, availability of organisations and individuals largely drove who was actually interviewed. Whilst acknowledging these limitations the researchers are confident the data are sufficiently robust to meet the objectives of exploratory research.

Training and learning among technical and trades personnel in the Australian R&D workforce

As expected, the qualifications held by trades and technical occupations in R&D varied markedly by context, particularly by type of R&D activity. All but one of the 71 trades and technicians we interviewed had a post-secondary school qualification, acquired either prior to entering into their current job or during their period of employment in the job. (The exception was a male nearly 70 years old, enormously experienced in his field, who had joined his current organisation organization prior to mandating of formal qualifications for specific positions.)

A total of 60 (86%) of those with an entry qualification had a vocational education and training (VET) sector qualification. These ranged from a Certificate 3 to an Advanced Diploma, with the most common qualification being a Certificate 3-4 (n=47). A high level of participation in post-entry training was evident amongst our participants, with 48 of the 71 respondents (68%) having undertaken additional training following their entry qualification. The most common was some level of Diploma (n=17) or a post-trade certificate (n=15). A total of 37 (77%) of the 48 additional qualifications attained were VET qualifications.

The respondents in our sample were much better qualified than the broader population of trades and technicians in Australia (see Table 2). Just 2% of persons in the sample did not have a post school qualification compared to 32% in the total population of technician and trade occupations. For 70% of all employed trades and technicians across Australia their highest qualification is a certificate 3-4. Amongst our sample, this level was the highest qualification of just 23%.

Table 2: Distribution of highest non-school qualifications in sample and total employed Technicians/Trades. Australia.

Qualification	Sample	Total Australia*
Postgraduate Degree	8.5%	1.2%
Graduate Diploma/Graduate Cert.	1.4%	1.0%
Bachelor Degree	12.7%	8.0%
Advanced Diploma/Diploma**	31.0%	10.4%
Certificate 3-4	22.5%	69.8%
Certificate 1-2	0.0%	7.1%
Certificate n.f.d***	22.5%	2.4%
Percentage with a post-school qualification	98.6%	68.2%

Source: (ABS 2007b Derived from Table 12)

* As at May 2006. ** Also includes Associate Diploma. *** Certificate not fully described. For the sample all of those with a Certificate n.f.d had in addition a minimum of a Cert 3 qualification.

The high rate of participation in further formal training appeared to be associated with the advanced technologies encountered in many R&D sites, along with the broader range of projects embodying distinctly different technologies that R&D workers encounter over the course of their working life. A total of 58% of participants indicated they had acquired additional qualifications specifically because of the R&D work they were doing. Assuming that trades and technicians are expected to actively engage in problem-solving and design with these technologies, this presumably requires higher level and broader skills and knowledge than provided by an initial qualification. Equally importantly, in most of the worksites visited possession of post-entry qualifications was a pre-requisite, or a strong expectation, for promotion into higher-graded technician positions.

There were some distinct patterns in participation in post-entry level training across the broad occupational groups. The majority (63%) of our sample were initially employed as apprentices and 18% in cadetship/traineeships (both these forms of training are part classroom-based and part on-the-job in the Australian system). The remaining 18% commenced as full-time students. A total of 31 of the 42 workers whose initial qualifications were gained via an apprenticeship also acquired an additional formal qualification, but only one of these was a university level qualification. In other words, whilst participation in post-entry level training is common for trade apprenticeship trained workers, with 74% acquiring an additional qualification, participation in university education appears to be uncommon.

The reason for the low rates of progression from higher level VET to university training was not investigated. Nevertheless, a number of possible causes can be ventured. The great majority of trades and technicians stated they liked their current role. Most also expressed a desire to avoid management responsibilities; these duties would, apparently, be part of promotion into positions requiring attainment of university qualifications. Finally, the respondents were on average mature aged, presumably with financial and family commitments, making it more difficult to devote time and money to university study. The low rate of progression of trade trained workers into university was not raised as an issue, either positively or negatively, by any respondent.

Of the 20 technician trained workers with a VET level entry qualification, eleven had acquired an additional qualification. Four (20%) had acquired a university qualification. Of the nine technicians with an under-graduate university degree as their entry qualification, five (56%) had completed additional higher level qualifications.

Respondents were asked to identify who provided their initial training. The public sector provided the initial employment and training for half (49%) the trades and technicians; the private sector close to one third (32%) with the remainder being full-time students who gained employment after or during their training (Table 3). Most of the full time students were at university. Over one-quarter (27%) of respondents remained with their initial employer. Thus close to three quarters of all respondents had been recruited into their current R&D workplace.

Table 3: Initial training X sector

Initial training employer	**Number trained**	**Percent of total**
Public Sector	35	49
- *Current employer*	*15*	*21*
- *Other employer*	*20*	*28*
Private Sector	23	32
- *Current employer*	*4*	*6*
- *Other employer*	*19*	*27*
Full-time Student	13	18
Total	**71**	**100**

The importance of the public sector as the initial training organisation reflects, in part, the disproportionate share of public sector respondents in the sample and the disproportionate role the public sector played in the training of apprentices and technicians in Australia up until the mid-1990s. The latter was due to high levels of public ownership of industries that are intensive consumers of trade skills, such as utilities, infrastructure and defence production, and unusually high rates of apprentice and other forms of training that occurred within the public sector (Toner 1998).

The pathway into R&D focussed employment had some fairly strong characteristics. The pattern of recruitment reveals that the great majority of trades and technicians employed in R&D are recruited externally and the principal providers of initial training and work experience for this external labour were public sector defence production and maintenance; public sector utilities and private manufacturing. Private sector manufacturing contexts of training among our participants included general engineering, defence contracting, food processing, telecommunications equipment production and servicing, and motor vehicle/components production. Many of these industries are primarily engaged in producing capital goods, whose principal output is the design and production of 'one-off' items. This is a very similar activity to much of the work undertaken by trades and technicians in their current R&D role.[3] The maintenance sector is the other large employer of tradespeople and all those with experience in this area had some relationship with manufacturing (e.g. shutdown contracting, or subcontracting).

[3] The capital goods sector has long been recognised as being both especially R&D intensive and as performing a critical role in the diffusion of innovation as new, more efficient production techniques are embodied in their output of new machinery and equipment (Smith 2004).

Regardless of the pathway into R&D almost all participants felt their initial training was valuable to their current occupations. Only two out of the 71 participants stated their formal qualifications were not useful. In both cases there were quite unusual circumstances contributing to why they answered in the negative. Respondents identified a broad range of skills, especially the use of tools and instruments and broader theoretical knowledge as the key useful qualities acquired through formal training. Unsurprisingly, the higher the level of initial training the greater emphasis participants gave to the utility of theory in their current role. The great majority of researchers also agreed that the acquisition of formal qualifications by trades and technicians was important in an R&D environment, explaining the higher level qualifications our participants had attained in comparison to the total employed population of these occupations.

OCCUPATIONAL ROLES, ACTIVITIES AND CONTRIBUTIONS TO R&D

Respondents were asked to describe their principal activities, the type of interaction they have with researchers and engineers, and to provide examples of their specific contribution to R&D. Overall, it was found that to perform these roles and make an active contribution to innovation in R&D, trades and technicians, as a general rule, had to be confident and comfortable with their own skills and knowledge and prepared to engage on occasion in 'robust exchanges' with senior scientists and engineers about designs *et cetera*. The importance of these attributes for VET workers engaged in R&D and commercialisation has also been noted elsewhere; '[t]hey need to be able to speak on the same level [as scientists], and...need...confidence for this' (AiG 2009: 24).

The activities of our sample can be summarised under five major headings.

(i) Use of tools, instruments and machines

A central role of all tradespeople and technicians related to the use of tools, instruments and machines. These occupations were responsible in part or whole for:

- identifying and sourcing equipment;
- installing and commissioning equipment;
- operating, maintaining, fault finding and calibration of tools and equipment;

- adapting equipment and instruments to perform novel functions or achieve particular performance characteristics required by a researcher;
- integration of systems (electrical, electronic; hydraulic and pneumatic, digital and analogue sensors etc.);
- explaining anomalous results from laboratory instruments, experiments or trials (this role derives from of familiarity with equipment and procedures arising from operation and or maintenance function)[4];
- writing up Standard Operating Procedures or technical reports for the operation and maintenance of tools and instruments; and
- collecting data from instruments and experiments for analysis by researchers.

(ii) Design function

Our participants commonly assisted researchers with the design of objects, instruments and experiments to conduct scientific tests, or introduce new or altered processes or prototypes for production. Involvement in design was identified by both trades/technicians and by researchers as a critical activity. This design role was found to be a function of their training and experience in practical problem solving; facility with tools and instruments; knowledge of materials, their properties and performance characteristics; skills in technical drawing and 3D design software programmes.

(iii) Linking R&D to production

In those sites where R&D and commercial production facilities were co-located, (which included all of the private sector sites in the sample,) trades and technicians involved in R&D could be important in integrating R&D results with production. For example, at a large food processing facility a food technician employed in R&D played an important role in transferring new products and production processes, such as new or adapted packaging

[4] A research manager in a CRC explained this role especially well. 'It is very important for us to be able to understand why a particular experiment has failed. The unexpected results are sometime perplexing. Often their [technicians] insights are because they have 1-2 decades working with this sort of equipment and undertaking many different sorts of tests. There suggestions about why a particular composite has failed are very helpful. This is generally across the board - not just one or so examples'.

equipment, to production by training production operators in its use and working with them to identify implementation problems. This important role was based on the fact that not only were they closely involved in the development of the new products and processes but, prior to becoming a VET qualified food technician, they also had extensive work experience on the factory floor operating mixing, processing and packaging equipment. This experience also enhanced rapport with the shop floor- ‘as he spoke their language’.

(iv) *Occupational Health and Safety (OH&S)*

A subsidiary, and unanticipated role, was applying safety rules and regulating access to dangerous environments and materials. OH&S is not only a central element in VET training of trades and technicians; it is also an important industrial relations issue. It became apparent that some scientists, and indeed some engineers, either from ignorance or a passion to conduct an experiment or test, can be a danger to themselves and others if they have unsupervised access to workshops or materials. Negotiations around machinery between technicians and researchers thus involved issues of safety and responsibility, along with questions of competence in obtaining results.

(v) *Teaching and learning*

Within the university laboratories that visited, we found trades and technicians are involved in teaching undergraduate and post-graduate students to use equipment, interpret results and assist with the design of experiments or projects. This was somewhat unexpected. Familiarity between post-graduate students and trade and technical workers who were located in the same or adjacent workshops was evident. Research students described the role trades workers had played in customising or adapting equipment crucial to their doctoral projects. This teaching role also applied to more obvious cases such to lab-based technicians setting up routine laboratory equipment in science class-rooms and providing instruction on its use. This role also applied to trades and technicians in Engineering workshops who assisted students in disciplines such as engineering and industrial design with designing, selecting materials and fabricating projects submitted for final year under-graduate and post-graduate studies. Another perspective on this role is that these, mostly VET trained workers, played a role in forming the new generation of scientists, engineers and designers.

A clear *in principle* demarcation of the roles of trades/technicians and researchers was expressed consistently and strongly throughout the interviews. We were fortunate to be able to interview scientists, engineers and technicians from the same project or functional teams in some cases. A fairly typical sequence was consistently described: ideas/questions (scientists) – representations, formulae, plans (engineers) – objects, instruments, prototypes, tests (trades/techs). However, we found that in reality in many research teams, particularly those with long-running projects or conjoint histories, there was a much less linear structure to the way activities would actually proceed than this skeleton might suggest. Often scientists spoke to trades and techs initially, or asked them to undertake idea-testing activities, particularly in relation to questions of feasibility and appropriate materials; this was frequently prior to spending too much time or effort trying to develop plans and elaborate ideas.

The great majority of researchers agreed strongly with the statement that trade and technical workers are an important source of ideas or innovations for the R&D conducted at their site. The predominant view of researchers was that it is the role of the technicians and/or tradespersons to assist in converting a concept into reality. Two different researchers described the process in these terms: "*[t]ranslate ideas to and from the scientists". "[t]urn the goals into technical reality after debates on costs".*[5] This contribution complements the primary role of the research scientist, which can be summarised as '*to define the problem and method of approach'*. Tradespeople and technicians also believe they make an important contribution to innovation in their work on R&D and the great majority of respondents provided specific examples of this contribution.

Many examples highlighted the development of highly sophisticated crafts skills and understandings of the properties of materials. The contribution of participants to design and problem solving was also evident.

> *...well one that took longer was a vacuum chamber that had to cool gas to an ultra-low temperature. Had a cryogenic chamber and I had to build something to pass the gas through. I made a copper chamber with a screw thread because I thought that doing it this way the gas would be inside the chamber for a longer time. It had to be modular so it could be switched in and out. It also had to machined to a very high tolerance. This one job took four weeks to get right.*

[5] A similar finding was made in the recent study into emerging technologies "In both research settings and commercial enterprises, emerging technology workers such as paraprofessionals and technicians need to translate what the design engineer (for example) has designed 'on paper' into something that will work in production (to ensure the design works in the 'real world')". (AiG 2009:26)

The construction of one-offs (such as the one described above), often without detailed (if any) drawings or specifications is part of R&D work at the material interface. Participants were also able to describe examples of the importance of their role to tasks of installation and customization of instruments or machines.

> *I had to design and make a stainless steel intermediary (ring/tube type fitting) for a vacuum chamber to fit a pump which had been supplied with holes the wrong gauge. It was from the US and needed a big adapter flange that was very expensive. I found a big lathe in another workshop and machined it myself. I've kept all the drawings and sketches that I do for projects like this in a folder. Solidworks data files too. The idea and the representations were part of the process, in the end I could only make the object if the equipment was available that had the capacity to do it, I was lucky I found we did…*

Responsibility for creating programming syntax and representations using computerised information technology, and for storing codified knowledge generated in the process of solving problems was also part of many of these occupations (as described above). Other descriptions portrayed the process of incremental innovation in standardised equipment or scientific instruments.

> *New equipment does come in on a fairly regular basis. Not usually life-changing but interesting. When we went from HPLCs to UltraPLCS we had new benefits in terms of what could be done, but also new problems. The manufacturer is often still perfecting, they were in this case, so reproducibility is an issue. Plus all the little things that require some serious use to prove their worth, valves, bubble sensors, hoses, all these hum drum parts. Our feedback helps them too, to improve aspects. For example with the UPLC we told them they needed to check the valves that help the pumps to control flow. We weren't satisfied with them and kept changing them. They kind of resisted us for a while but we kept telling them what was happening, then suddenly a new check valve system appeared!*

As this description highlights, technical occupations often 'broker' the connections between the suppliers and users of complex equipment, providing the kinds of information loops that are crucial for incremental innovation. Worker at the material interface thus also mobilize distributed networks' in efforts to 'iron out' bugs – even in standardised commercially re-produced equipment.

Benefitting from these types of capabilities embedded in the highly skilled technical workforce appeared, throughout the study, as irreducibly tied to work organisation. In particular, trades, technicians and researchers agreed that the timing of contributions made by technicians to the R&D process is as crucial as its substantive content.

> *…the earlier they [researchers] come the better we can help, the more clarity for us in what we have to do. The 'have you thought of this or that discussion', it saves a lot of time and energy.*

Initial conceptions of scientific or commercial problems, that constitute the object of R&D activity, precede a decision to proceed with a project or activity. Establishing parameters of material feasibility is therefore viewed as crucial.

> *Many researchers have great ideas about what to do and even a schematic idea of how to do it. But nearly all have limited ideas of what is the best material to use to do it.*

There is variation in the precise point at which input from trades or techies occurs, however it was repeatedly emphasised that 'early involvement' can clarify possibilities and avoid wasted time and 'dead ends'. Tradespersons and technicians thus described being frequently involved in providing advice to scientists and researchers on feasibility of various design options, identifying suitable materials and estimating cost of manufacture or acquisition. The timing of this involvement reflects important differences in terms of hierarchy and authority across the principal occupations involved in R&D, as well as social and personal relationships prevailing in particular work environments. The timing of trade/tech involvement in R&D projects appeared significantly tied to R&D work organisation arrangements, as discussed further below.

The boundaries between researchers and technical occupations were also evident from descriptions of interactions and examples of collective work. One clearly demarcated difference between scientific researchers and others was responsibility for conception and initiation of research programs and projects. Researchers, with a science or engineering background, are responsible first, for the original conception of an R&D project consistent with the broad research parameters set by the R&D organisation. The researcher has to clearly specify the objectives of the R&D project and the scientific or engineering principles that underpin the project. Second, researchers are responsible for management of the budget and selection of personnel to be involved.

There are important caveats to this account of both roles. In some instances the 'original conception' for an R&D project, especially in the private sector, can come from a marketing or sales department. These departments typically are responsible for identifying market opportunities that may require the involvement of an R&D department to better align a firm's product or service range with changing market needs. The scientific and engineering work required to implement such changes, and the management of change is the responsibility of the researcher. We also identified instances where, because of their breadth of technical and organisational knowledge and project management experience, VET trained technicians are appointed as project managers on large R&D projects after a decision has been made to proceed with the R&D project.

There are many reasons for this intellectual and manual division of labour between trades/technicians and researchers aside from the obvious influence of differences in the content of initial training. Senior university-based researchers observed of themselves and among their peers an atrophying of 'bench practice'. These researchers observed they had developed considerable competence in laboratory practice in the course of their post-graduate training but these skills had diminished over time. This was because of the job design of academics, who are too busy teaching principle or theory based classes, applying for grants, writing-up research or attending conferences. Senior researchers in the private sector also identified the limited career path for science and engineering researchers which, in effect, requires those seeking promotion to leave the benchtop and enter management.

WORK ORGANISATION AND TECHNICAL OCCUPATIONS IN R&D

The study found that work organisation systems are critical in mediating the quality of working life of trades and technicians in R&D and, arguably, the performance of R&D. In summary, interviewees were especially critical where there was a perceived 'separation of conception from execution' in their workplace. This separation was caused by inadequate communication between people charged with designing an experiment or a new or modified product, service or production process and those responsible for conducting the experiment or making, maintaining or delivering the changes.

The importance of timing and coordination of involvement for technical occupations is reinforced from this perspective. One fitter machinist outlined clearly the benefits for both the researcher and the tradesperson of early communication:

> *some engineers come down and ask about whether a design is possible in our opinion, particularly things like size limitations, scale issues. Some of the engineers always or*

> *at least regularly do that, this saves everybody hassle as it eliminates designs from the system that can't and won't be done. If an engineer needs to know if it is worth pursuing a particular path with a design he will sometimes ask us to knock something up, if it's only going to take 20/30 minutes, then he can pre-test his idea. Once again, saves a lot of unnecessary time wasting later.*

Job satisfaction amongst technical workers was closely linked to this issue. The key attractor of R&D was the variety of work, but this also varied according to opportunities provided to multi-skill and to work across teams. A high value was accorded by trades and techies to active engagement in problem-solving, particularly when there was recognition of their contribution that went beyond an assumption that this was merely routine execution of plans or blueprints.

Our participants also valued access to training and learning new skills; exposure to new technology; higher job security (at least in the public sector and larger private firms) and work organisation systems and colleagues that treated them with respect and encouraged their active engagement in innovation. The majority of respondents reported how intrinsically satisfying they found R&D work such as working on prototypes of medical and diagnostic instruments; environmental research; developing new resistant crops; healthy food products or national defence. This conclusion is confirmed by their responses to specific questions regarding the organisation of work at their workplace. The majority of respondents stated they were involved early in new R&D projects, had some control over the allocation of work, felt encouraged to contribute to innovation, and believed their skills and capabilities were recognised and utilised. A clear finding of the study was thus that trades and technicians self-select to enter and, more especially, to remain in R&D because of these attributes of the job.[6]

There were five major factors that emerged from our data in relation to work organisation, technical work and R&D. First, was the apparent advantage of small, cohesive project teams. Crucially, it was the integration of different yet complementary forms of knowledge and types of skill into a communicative unit that seemed to matter most. The differences and complementarity of skills and knowledge across scientists, engineers, technicians and tradespeople are explicitly recognised within the team, and work organised to take advantage

[6] This aspect was also expressed in the negative, with many workers with prior experience of a production and/or maintenance setting identified a number of unattractive aspects of their previous work. These included a dislike of routine; lack of autonomy; dis-engagement from innovation and the intense pressure to be found in a production or maintenance setting where ‘getting the product out’, sometimes at the expense of quality, is the principal objective

of these complementary skills in a timely manner wherever possible. These teams are either ‘permanent’ in that are devoted to undertaking projects in a particular technology specialisation, such as microelectronics, or researching particular viruses or pathogens or ‘project based teams’ developed on an *ad hoc* basis to undertake one-off projects. Within the public sector R&D agencies we found example of both; members were typically drawn from semi-permanent teams in defence, whilst a ‘matrix management’ structure underpinning a capability approach was used in a multi-sector agency. Examples of both are also found in the private sector with the addition that because of high volatility in R&D expenditures, ad hoc teams are often drawn from non-R&D sources such as production, marketing and external short term contractors.[7]

Second, a balance needed to be struck between stability and the infusion of new talent or trainees. Most of the interviewees in the public sector were long-term employees with deep experience in technical fields and understanding of how other team members operate. A related advantage of relatively good job security is that, as explained by a mature age female electrical apprentice, team members do not have to worry about sharing information with each other and ‘someone trying to take your job’.[8] Whilst lengthy job tenure develops cohesive teams and a ‘deep corporate knowledge’ and skill base related to the specific R&D of the organisation it does need to be supplemented with a certain inflow of new skilled people who have experience of other technologies, organisations and ways of solving problems.

Third, most participants placed a high value on team members working in close physical proximity to each other. This was crucial to facilitate ready exchange of information and problem-solving. For example, close proximity means people being able to meet and make

[7] This latter aspect of private sector teams was also found by DIISR officers involved in the 2007 DITR report on volatility in R&D expenditures (Personal communication). Shifting skilled staff across R&D, maintenance or production due to cycles in R&D expenditure in the firm is one way of retaining a core of R&D staff. It also has the advantage of R&D staff developing greater knowledge of those parts of the organisation charged with implementing innovations.

[8] In some workplaces visited, managers, trades and technicians complained about the relatively high turnover of young R&D engineers. The long tenure of many trades and technicians, it was suggested, provided an anchor for corporate memory. “People come and go particularly management but trades and techs always stay the same - this stability in the workshop and the longevity of the labour and its skills make it possible for them to make almost anything for the changing group of scientists or their projects” (47 year old fabrication trade 11 years with public sector R&D agency). A female technical officer in a private defence contractor commented on her training role with young engineers she regularly encounters and refers to the latter as ‘my apprentices’.

quick changes in designs; to instantly see and handle a prototype; and to immediately test the prototype with the designers and/or maker being present to see how the prototype performs and how it can be improved.

Four, it was a strong finding that forms of organisation that facilitate opportunities to actively contribute to early concept planning, iterations of designs and prototypes, were much preferred. Active participation in design and problem-solving is actually expected of all members and, crucially, these contributions are recognised either informally within the team or more formally through recognition in scientific papers, presentations of awards, gifts or even cash bonuses. Teams that met regularly, particularly early in a project, with all aspects of the occupational structure involved were correlated with better reported team spirit and collaborative philosophy. Many participants were able to give examples of contexts in which such a relatively flat structure did not characterise project management and coordination – with a uniformly negative impact on efficiency and workplace relationships. On the other hand overly centralised workshop structures could result in engineers whose primary concern is workflow management becoming interposed between trades/techs and researchers/designers. A related finding for corporations with discrete R&D, production and marketing divisions seemed to be the importance of integrating these functions at each stage in the R&D process.

Finally, R&D worksites seem to place a strong emphasis on continuous training, supported either in the form of short courses that fill skill gaps or longer term post-entry level VET or university training that lead to formal qualifications. Multiskilling is also encouraged within the teams. Many participants said they had the possibility of undertaking formal training, but not the opportunity – due to the demands of day to day workflow rather than any perceived barriers to training.

Positive outcomes appeared only in part to be the outcome of well-planned and well implemented organisation-wide systems. They were often the result of good practice on the part of individual researchers and/or good practice within small teams. As noted by many trades and technicians too often good practice was also the result of the ‘personality’ of particular researchers. When asked about the presence and effectiveness of formal employee participation programmes directed at continuous improvement at their workplace a minority of respondents identified such a system operating and a majority were ambivalent about its effectiveness. Crucially, whether trades or technicians felt they were encouraged to contribute to innovation was independent of whether a system to reward or recognise their contribution to innovation operated at their workplace.[9]

However, a significant minority of trades and technicians were critical of the openness of communication with scientists and researchers at their worksite, and claimed to have sought earlier and greater involvement in the R&D process. They revealed a perception that some researchers do not understand the importance attached by trades and technicians to their engagement in the R&D process, or that creating opportunities for deeper involvement could, arguably, improve overall performance in the workplace. This outcome was felt possibly to be a result of the fact that work organisation issues and staff management are typically not given prominence in the professional training of scientists and engineers.

DISCUSSION AND CONCLUSION

Trade and technical occupations appear to play a significant role in R&D and make direct contributions to innovation of various types. In terms of incremental innovation participants described themselves as involved in customization and development of instruments and machines. Contributions to more radical forms of innovation associated with problem-solving and project feasibility were also in evidence. Participants in the Australian study appeared to largely self-select for this type of work – due to the variety of tasks, the opportunities to develop skills and desire to contribute within a holistic rather than a Fordist type of work structure. Public sector agencies appeared to be a very important training ground for these R&D occupations. However, many individual workers also brought knowledge and skills across from private industry, whilst playing an important linking role between R&D and production in many contexts.

That highly skilled trades and technical workers have the capability to make a contribution that is innovative, and advances innovations, seems to be in little doubt. However, exploiting

[9] There appeared to us to be some conflict between statements that, on the one hand, interviewees said recognition of a contribution they make to innovation is important to them and, on the other hand, whether people felt encouraged to contribute to innovation was independent to some extent on whether a formal system of recognition existed at their workplace. Respondents appreciated recognition, but often this came informally from their team or simply an email from a scientist in the field who had successfully used a device made by the trade or technician. There were also some problems with the perception of the fairness of the operation of some formal recognition and reward systems.

this capability, and the extent knowledge, product or process benefits can be extracted from it, seems to be very much dependent upon variables of work organisation. The contribution of technical occupations in an R&D context of basic research was enhanced at worksites where coherent project teams, in their entirety, were involved in projects from the early planning phase onward. At this stage technical workers could often provide important inputs, such as ‘knocking together’ an object to test some formative ideas or hypotheses. In private R&D focussed on product development technical workers seemed uniquely placed to link R&D, quality control and production, being able to speak the requisite language across functional boundaries. In both contexts, the material interface of work in which trades and techs perform their core tasks, also appeared to be the most important site for integrating ways of knowing and resolving problems. On the negative side, teams in which there was more of linear and segmented work organisation structure seemed relatively inefficient, and were definitely less rewarding environments for technical occupations. Adequate levels of recognition and reward, whether direct and informal acknowledgement of contribution from upper echelons of organisation hierarchy or via a formal innovation or continuous improvement process, was also seemingly connected to work organisation variables.

In many developing countries there are policy concerns about ‘brain drain’. This includes a concern about the permanent loss of scientists and engineers as well as skilled technical and trades workers. We see this as potentially two parallel but inter-related problems. There is now considerable accumulated evidence that scientists and engineers from developing leave their home countries to pursue their careers among countries of the North partly due to the more limited human resource infrastructure ‘at home’ (Turpin *et al*, 2010). The study described in this paper suggests that while technical and trades workers can make very significant contributions to innovation in R&D settings, these contributions are maximised in contexts where work organisation is conducive to their broad involvement and where investments in technical infrastructure and complementary human capital have been made. In developing countries where there is a loss of both scientists and engineers *and* trades and technical workers from R&D sites these can become mutually compounding problems. That is, scientists and engineers may leave because of an inadequate supply of trained technical support and highly skilled technical staff may leave because they lack the opportunity to engage more directly in the R&D process. A policy implication is that simply focusing on encouraging return or involvement of expatriate scientists and engineers, without addressing the need for adequate technical support infrastructure, will achieve little in the long term.

The research consolidated some of the assumptions and broad hypotheses that we took into the research. The findings support broad assumptions about the importance of skills for innovation and the potential benefits for economic development. Participants also seemed to operate in roles that bore more than passing resemblance to those termed ‘buffers’ and ‘brokers’ in the US context of technical work (Barley’s 1996). However, in many Australian R&D contexts the technical occupations also seemed to play an important role as integrators of different forms of knowledge. This is probably an impression that needs to be explored more fully before it can be claimed that there are a set of activities that ‘integrate’ in a distinguishable and definable way. It may be that the concept of ‘boundary object’ could have a role in exploring this aspect of technical occupations in R&D.

The research also opened up other questions that we think need further exploration. One of these is to gain better insight into the career variables that structure R&D careers amongst vocationally trained workers. The ongoing augmentation of craft-based skills appears one attractor to R&D intensive work, however, without more detailed exploration of career paths and structures this remains unconfirmed and merely a correlate of our observation that our participants seemed to ‘self-select’ for R&D work. The institutional capacity to sustain the supply of the kinds of high level skills required for R&D work also emerged as an important question in the course of our study. With the decline of public sector organisations as training powerhouses there are reduced contexts in which apprentices and trainees can gain the kind of early career experience that rotation through large R&D preforming organisations allows. This seems particularly important given the apparent reliance of the most highly qualified knowledge workers in the economy, scientists and engineers, on other diverse skills and occupationally based forms of knowledge. An important insight relevant for developing economies relates to this apparent fact. It seems crucial not to overlook, or lose focus upon, the provision of skills and knowledge embedded in these technical occupations in the rush to add higher degree researchers (HDRs) to the economy, when deriving maximum benefit from the presence of scientists and engineers appears to rely significantly on the availability of complementary human capital.

References

ABS (Australian Bureau of Statistics) (2005) *Information Paper ANZSCO – Australian and New Zealand Standard Classification of Occupations*, ABS Cat. No. 1221.0

ABS (2005a), *Innovation in Australian Business 2003*, Cat. No. 8158.0.

ABS (2005b), *Research and Experimental Development. Business Australia 2003-04*, Cat. No. 8104.0.

ABS (2005c), *Australian System of National Accounts 2004-05*, Cat No. 2504.0.

ABS (2006a), *Australian and New Zealand Standard Classification of Occupations*, Canberra.

ABS (2006b), *Innovation in Australian Business 2005*, Cat. No. 8158.0.

ABS (2006c), *Research and Experimental Development. All Sector Summary Australia 2004-05*, Cat. No. 8112.0.

ABS (2007a), *Research and Experimental Development, Business. 2005-06 Australia*, Cat No. 8140.0.

ABS (2007b) *Education and Work Australia*, Cat No. 6227.0

Amin, A. and Roberts, J. (2008), "Knowing in action: Beyond communities of practice", *Research Policy* Vol. 37, pp. 353–369.

Anderton, R. & Schultz, S. (1999), *Explaining export success in the UK and German medical equipment industry*, Discussion Paper no.185, Anglo-German Foundation, London.

Australian Industry Group (2009) *Profile of Emerging Technologies and Implications for the Vocational Education and Sector*, Sydney.

Barley, Stephen R. (1996) Technicians in the workplace: Ethnographic evidence for bringing work into organization studies, *Administrative Science Quarterly*, Vol. 41, 404-441.

Barley, Stephen R. & B. Bechky. (1994) In the backrooms of science: Notes on the work of science technicians." *Work and Occupations,* Vol. 21, 85-126.

Barley, Stephen R. & Julian. E. Orr (eds) (1997) *Between craft and science. Technical work in U.S. settings*, ILR Press/Cornell University Press*,* Ithaca and London

Bechky, Beth A. (2003) 'Sharing Meaning Across Occupational Communities: The Transformation of Understanding on a Production Floor', *Organization Science* 14(3): 312-330.

Bechky, Beth A. (2006) 'Talking About Machines, Thick Description, and Knowledge Work', *Organization Studies*, 27(12): 1757-1768.

Bruland, K. (2003), Education. I: *The Oxford Encyclopaedia of Economic History*. Mokyr J. (ed) Oxford University Press: 160-170.

Crouch, C., Finegold, D. & Sako, M. (1999), *Are skills the answer? The political economy of skill creation in advanced industrial countries*, Oxford University Press, UK.

Edquist, C. (2005), "Systems of Innovation: Perspectives and Challenges", *The Oxford Handbook of Innovation,* Fagerberg J., Mowery D. C. and Nelson R. R. Oxford University Press, UK**:** 181-208.

Hermann, A.M. & Peine, A. (2011) 'When 'national innovation system' meet 'varieties of capitalism' arguments on labour qualifications: On the skill types and scientific knowledge needed for radical and incremental product innovations', *Research Policy*, 40: 687-701.

Hippel, E. von (1988), *The sources of innovation*, Oxford University Press, New York (2005) *Democratizing Innovation*, MIT Press, Cambridge, United States.

Johnstone, Ivan & Pauline Robinson (1997) How Enterprises Can Foster Creativity: Three Australian Case Studies, *International Conference on Creativity Development in Technical Education and Training*, National Taiwan Normal University, Dec 2-3

Kim, Young-Hwa (2002), "A State of Art Review on the Impact of Technology on Skill Demand in OECD Countries", *Journal of Education and Work*, Vol. 15, No. 1, pp.89-109.

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

OECD (2006), *Main Science and Technology Indicators*. Volume 2007/1, Paris.

Orr, Julian E. (1996) *Talking about Machines. Ethnography of a Modern Job*, ILR Press/Cornell University Press, Ithaca and London

Osterman, Paul (ed.) (1996) *Broken Ladders: Managerial Careers in the New Economy*, Oxford University Press

Prais, S. (1995), *Productivity, education and training: An international perspective*, National Institute of Economic and Social Research, Occasional Papers XLVII, Cambridge University Press, Cambridge.

Shapira, Philip (ed.) (1995) *The R&D Workers: Managing Innovation in Britain, Germany, Japan and the United States,* London, Quorum Books.

Thelen, Kathleen (2004) *How Institutions Evolve. The Political Economy of Skills in Germany, Britain, the United States and Japan*, Cambridge University Press, UK.

Toner, Phillip (1998) Trends in NSW Government Apprenticeship Intake: Causes and Implications, *Australian Bulletin of Labour,* Vol. 24, No. 2, June, 141-157.

Toner, Phillip (2011) ‘Workforce Skills and Innovation: An Overview of Major Themes in the Literature’, *OECD Education Working Papers*, No. 55, OECD Publishing. doi: 10.1787/5kgk6hpnhxzq-en

Trompette, Pascale & Domique Vinck (2009) ‘Revisiting the notion of Boundary Object’, *Revue d’anthropologie des connaissances*, 3(1): 3-25.

Turpin, Tim, Richard Woolley and Jane Marceau (2010) ‘Scientists across the boundaries: national and global dimensions of scientific and technical human capital (STHC) and policy implications for Australia’, *Asia Pacific Migration Journal*, Special Issue on Labour Migration, **19**(1): 65-86.