Journal of Vocational Education & Training

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rjve20

Innovation, technician skills, and vocational education and training: connecting innovation systems and vocational education and training

Paul Lewis

JOURNAL OF VOCATIONAL EDUCATION & TRAINING
https://doi.org/10.1080/13636820.2023.2215749

Innovation, technician skills, and vocational education and training: connecting innovation systems and vocational education and training

Paul Lewis

Department of Political Economy, Bush House North-East Wing, King's College London, UK

ABSTRACT

The paper adds to the literature on vocational education and training by developing an account of the role played by technicians, and vocational education and training, in innovation. It also fills a gap in the innovation systems literature by analysing the neglected role of technicians and providers of vocational education and training in innovation. It outlines technicians' contribution to innovation, sets out a theoretical framework for analysing the role of providers of vocational education and training in the innovation system, and discusses what 'system failure' involves in this context, as well as possible policy responses, using England as a case study.

ARTICLE HISTORY
Received 6 June 2022
Accepted 3 May 2023

Keywords
Technicians; innovation; innovation systems; apprnticeships; training; system failure

1. Introduction

The goal of this paper is to highlight and then help to fill a gap in the innovation systems (IS) literature. The gap results from that literature's relative neglect of the role of technicians – that is, workers occupying roles requiring 'intermediate-level' skills and knowledge in science, technology, engineering, and mathematics – in innovation.

'Innovation' is the 'implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations' (OECD 2005, 46; also see Borrás and Edquist 2019, 16–17). It involves not only the creation of new products and methods of production but also their widespread diffusion and adoption through the economy. It is the process through which new knowledge is created and applied in order to raise productivity, output, and living standards (BIS 2011, 1–2, 7–22; OECD 2005, 46–52, 2015a, 3–4)

Perhaps the most prominent and influential approach to the study of innovation is the innovations systems (IS) approach, which has risen to prominence

CONTACT Paul Lewis paul.lewis@kcl.ac.uk

over the past thirty years (Dosi et al. 1988; Lundvall 1992; Edquist 1997a; Lundvall 2007; Borrás and Edquist 2019, 15–36). An IS is the network of organisations and institutions involved in the production, diffusion and use of knowledge about new technology (Lundvall 1992, 2; Edquist 1997b). The key idea underpinning the IS approach is that, far from being driven simply by fundamental research and development, innovation is a non-linear process that involves firms interacting with many other kinds of organisations as they attempt to devise, develop and deploy new technology. Those other organisations include universities, banks, regulatory and standards-setting agencies, and – last but not least – providers of VET. They help to supply firms with the knowledge, finance, and skills required for innovation to take place (Smith 2000, 92–93, Smith 2010, 85–86). The institutions are the rules governing the interactions between those organisations. They include the rules of corporate governance, contract and intellectual property law, and the terms on which government support is provided for various kinds of education and training. Innovation is an 'instituted' process (Metcalfe 2005, 50) because the rules structure how the organisations involved in innovation interact with one other, thereby shaping how successfully firms are able to innovate (Nelson and Rosenberg 1993, 3–5; Lundvall 2007; Edler and Fagerberg 2017).

One significant influence on innovation is a country's education system. The latter is of course important because of its role in generating the skills needed to develop and deploy new technologies (Metcalfe 2005: 50, 68–69, Metcalfe 2007, 449–50; Makkonen and Lin 2012; Crafts and Hughes 2013, 3–4, 13, 21; Bessen 2015: 222–25; OECD 2015a, 13–14). However, when discussing the role of skills, and the organisations that contribute to their production, the IS literature has tended to focus on universities and highly-qualified graduates and researchers. Such workers make an important contribution to innovation by driving the research and development activities through which many new ideas are created (BIS 2011, 111–14; Jones and Grimshaw 2016, 109). But far less attention has been paid to the contribution made by technicians and by the providers of vocational education and training (VET) through which technicians acquire their skills and knowledge.[1] Technicians play a significant role in innovation, contributing both to firms' absorptive capacity – that is, their ability to make effective use of new technology – and also by suggesting incremental improvements to technology (Lewis 2019: 10–12, 18–21; Mason 2019, 13–14). However, even on the few occasions where technicians and VET providers are mentioned in the IS literature, the discussion tends to be short and under-developed (see, for instance, Nelson 1992: 351, 358–59; Nelson and Rosenberg 1993, 13; Edquist 1997b, 20; Edler and Fagerberg 2017, 11–13; Fagerberg 2017, 504).

This lacuna has not gone unnoticed. Borrás and Edquist (2019, 29) have recently observed that there is 'little detailed knowledge about the ways in which the organisation of education and training influences the development and diffusion of innovations'. Another recent contribution states that 'there is a lack of attention in the innovation literature to the question of how we theorise and empirically analyse the multiple linkages between the components of skill formation systems and their varying innovation effects' (Jones and Grimshaw 2016, 124). These lacunae reflect the way that, as another recent paper states, 'Traditionally, the IS approach … incorporates universities as the main knowledge institutions connected to innovation, neglecting the relevance of vocational education institutions in relation to innovation.' One consequence, the authors continue, is that 'vocational education and training … colleges [are] under-researched knowledge institutions in empirical studies on innovation systems' (Lund and Karlsen 2019: 4, 2).

There are signs, however, that the situation is changing, with the recent publication of several papers exploring the relationship between VET, technician skills, and innovation from an IS perspective (Toner 2011; Borras and Edquist 2015; Toner and Woolley 2016; Brunet Iscart and Rodríguez-Soler 2017; Porto Gómez, Zabala-Iturriagagoitia, and Aguirre Larrakoetxea 2018; Lund and Karlsen 2019; Mason, Rincon-Aznar, and Venturini 2019; Lewis 2019, 2020; Rupietta and Backes-Gellner 2019). The goal of the current paper is to contribute to this small but growing body of research on how the role of technicians, and providers of VET, can be incorporated into the IS approach. More specifically, the paper's contribution is fourfold: (i) it outlines the kinds of contributions technicians make to innovation (Section 2.1); (ii) sets out a theoretical framework that can be used to conceptualise the role of providers of VET in equipping workers with the skills and knowledge they need to contribute to innovation (Section 2.2); (iii) discusses what the notion of 'system failure' involves in the case of VET (Section 2.3), with particular reference to the situation in England (Section 3); and (iv) examines how, notwithstanding such problems, it sometimes remains possible to bring firms and education providers together in ways that make the creation of suitable programmes feasible, outlining the type of 'institutional architecture' - the kind of organisations and institutional rules – that help to make such successes possible (Section 4). Section 5 summarises the argument and highlights its broader significance for innovation policy, as well as identifying opportunities for future research.

2. The innovation systems approach and technical education

This section of the paper examines the importance of technician skills and training in developing firms' capacity to innovate, and the role of VET providers in supplying those technicians. As noted above, technicians are workers occupying roles that require 'intermediate-level' skills in science, technology, engineering and/or mathematics. They use their knowledge of those disciplines, and related practical skills, to solve practical problems arising in research and development, production, and maintenance. They contribute to innovation in two main ways: by contributing to the capabilities of the firms that employ them to deploy new technologies; and by identifying ways in which equipment, processes and products that are already in use can be incrementally improved.

2.1 Technicians' contribution to innovation: absorptive capacity and incremental innovation

A firm's 'absorptive capacity' is its 'ability … to recognise the value of new, external information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal 1990, 128). It is the firm's ability to understand and make effective use of new knowledge and innovative technologies. Two main aspects of absorptive capacity may be distinguished: *potential* absorptive capacity, defined as the ability to identify and acquire relevant external knowledge of new technologies; and *realised* absorptive capacity, which refers to the capacity to apply that knowledge to good effect within the organisation (Zahra and George 2002).[2] A key influence on a firm's absorptive capacity is the skills and knowledge of its workforce (Cohen and Levinthal 1990, 129–33). Very highly qualified engineers and scientists play a significant role in identifying new technologies, thereby contributing to potential absorptive capacity. But once that knowledge has been identified, a firm's technicians make an important contribution to its ability successfully to deploy it in the workplace, thereby contributing to the firm's realised absorptive capacity (Jones and Grimshaw 2016, 113; Porto Gómez, Zabala-Iturriagagoitia, and Aguirre Larrakoetxea 2018; Mason, Rincon-Aznar, and Venturini 2019; Rupietta and Backes-Gellner 2019).

The reason is that the effective deployment of technology to bring about improved operational performance depends upon the ability of technicians to instal, adapt, operate, troubleshoot, and maintain it. For example, technicians are involved in the installation, commissioning, maintenance and improvement of plant and facilities in the chemical industry and in industrial biotechnology (Lewis 2013b, 13–15, Lewis 2016b, 20–22, 25) and also in implementing new manufacturing processes in the advanced therapies sector (Lewis 2016a). Technicians play a critical role in helping car manufacturers realise the potential for changes in technology and work organisation to reduce costs and improve output quality (Mason and Wagner 2005). The increasingly widespread use of composite materials in the aerospace and high-end automotive sectors depends upon technicians being skilled at using and repairing such components (Lewis 2012a, 2013a). The ongoing move towards the automation and digitalisation of manufacturing presupposes that workers possess the skills and knowledge to deploy those new technologies (Pfeiffer 2015, 16–19; Lund and Karlsen 2019; HVMC and Gatsby 2020, 6–8, 15–16).

A firm's realised absorptive capacity will be greater if its technicians have broad, occupationally-oriented skills, coupled with a sound understanding of the relevant theoretical principles, than if they possess only narrow, job-specific skills and little underpinning knowledge. Technicians with a wider range of skills and good underpinning knowledge are more likely to have the competences (Borrás and Edquist 2019, 86–88) required to use new technology effectively than those with narrower skills sets and little underpinning knowledge (Tether et al. 2005, 6–7, 55–56; Toner 2011, 33–36, 45–48; Toner and Woolley 2016, 329–31).

Technicians also contribute to incremental innovation (Rosenberg 1976, 1982; Smith 2005, 150–51). As a recent report has put it, 'innovation does not stop at the doors of R&D departments. It arises in the interplay between a wide range of disciplines and departments, right across the product lifecycle' (Pfeiffer 2015, 16). Technicians' practical experience of operating, maintaining and solving problems with equipment and production processes leaves them well placed to identify how that technology can be improved, thereby enabling them to contribute to the creation of the knowledge required for incremental innovation (Beesen 2015: 11–14; Lewis 2019: 10–12, 18–21; Mason 2019, 13–14; Felstead et al. 2020). This of course exemplifies the general point made by IS theory, namely that the knowledge that informs innovation derives not just from R&D but also from several other sources.

2.2 Conceptualising the role of VET providers

If, as suggested above, technicians have a potentially important role to play in innovation, the question arises of how appropriately skilled technicians can be developed. This turns the spotlight onto education and training providers. A recent article that is helpful for analysing this issue is Vona and Consoli (2014). While they focus primarily upon universities, and graduates, their approach can also be used to analyse the role of VET providers in equipping technicians with the intermediate-level skills and knowledge needed to deploy, and incrementally to improve, new technologies.

The key idea is that of 'knowledge systematisation', defined as the 'standardisation of novel best practices and … their diffusion by means of changes in the content of education and training' (Vona and Consoli 2014, 1394). This is used as a conceptual vehicle for connecting technology, institutions and skills. According to Vona and Consoli's 'life cycle' approach, when a new technology is first developed the activities required to deploy it tend to be complex, poorly-defined, and the exclusive preserve of a small number of very highly-qualified researchers. Knowledge of how to operate the technology is mostly tacit, so that its transfer requires personal interaction. Over time, however, the technology matures and it becomes possible to codify the relevant knowledge in the form of standard operating procedures, thereby facilitating the use of the technology by less highly-qualified people such as technicians (as the efficient scaling-up of production demands). It is at this juncture that VET providers have an important role to play, because they need to be willing and able to offer programmes through which workers can acquire the requisite skills and knowledge (Vona and Consoli 2014, 2014: 1394–99, 1404; also see Bessen 2015: 20–24, 52–57 140–42; Gómez *et al*., 2018).

We can elaborate on this point by drawing on another important recent contribution, namely Rupietta and Backes-Gellner (2019). While not using the term 'knowledge systematisation', Rupietta and Backes-Gellner outline a similar process to that set out by Vona and Consoli, relating it to the distinction between STI (Science, Technology and Invention) and DUI (Doing, Using, Interacting) modes of innovation and learning (Jensen et al. (2007). More specifically, Rupietta and Backes-Gellner (2019, 572–75) set out a four-stage process through which VET curricula in Switzerland are updated to reflect the requirements of new technology.

- The first stage, 'knowledge collection', centres on firms that have been developing new technologies through a DUI approach, whereby people learn how to use them through close interactions with more proficient colleagues. This first stage involves 'social partners' such as employer organisations harvesting information from those firms about what skills and knowledge technicians need in order to operate the technology effectively. In this way, innovative firms provide an input of knowledge into the broader innovation system.
- Second, the social partners synthesise and codify that information, identifying the (general, occupationally-oriented) skills and knowledge needed to deploy the technology and using it to develop revised training curricula. This process of 'collective knowledge synthesis' makes it possible for tacit knowledge that could hitherto be transferred only via personal interaction falling under the DUI mode of innovation to be made explicit and thus to be disseminated in ways that reflect the STI mode of innovation.
- The third step, 'knowledge transfer', sees the updated curricula disseminated to all firms that train apprentices, with the government mandating that instructors in firms and training providers attend courses to prepare them to teach the new material.
- Fourth, knowledge is transferred back to firms as their apprentices learn from the updated curricula, helping firms to develop the absorptive capacity needed to make good use of new technologies at scale ('Knowledge application').[3]

This example shows that, if innovation involves learning about new products and methods of production (Lundvall and Johnson 1994), and if the requisite knowledge includes an awareness of the competences required for technicians to play their part, then there needs to be a mechanism through which knowledge systematisation takes place (that is, through which training providers can identify the skills and knowledge firms need to assimilate new technologies).

Rupietta and Backness-Gellner draw on the example of the Swiss VET system, which is renowned for its high-level of performance (reckoned in terms both of the quality and quantity of apprentices it produces) (Wolter and Ryan 2011, 543–46, 566–69; Gonon and Maurer 2012). All stages of the knowledge systematisation process appear to work well. However, not all VET systems are as successful in supplying firms with the up-to-date skills needed to deploy new technologies in a timely manner. This brings us to the possibility of 'system failure', to which we turn in the next section of the paper.

2.3 System failures in the case of VET

If VET providers do not offer the relevant programmes in a timely manner – because the rules governing their behaviour discourage them from doing so, or because there is no mechanism through which they can easily learn about emerging skills needs – then the education and training system may fail to coordinate the accumulation of human and physical capital. For instance, education and training providers may devote too many resources to the development of one kind of worker (graduates, say) whilst neglecting the education and training of technicians. As we will see below, such coordination failures can lead to structural mismatches between the stocks of physical and human capital that manifest themselves in problems such as shortages of technicians, deficiencies in technician skills, the use of overqualified but under-skilled graduates in technician roles, and problems in persuading training providers to offer the apprenticeship programmes needed to train technicians (Amendola and Vona 2012, 632–34; Vona and Consoli 2014: 1400–02). Such problems constrain the absorptive capacity of firms, limiting their ability to exploit the potential of new technology (Chaminade and Edquist 2010, 104; DBIS 2014: 22–23).[4]

Such failings are 'system failures' in the sense that the institutional framework within which innovation occurs does not coordinate all the activities needed for the satisfactory diffusion of new technologies (Chaminade and Edquist 2010, 101–05; Smith 2010, 89–90; Breda and Del Rio 2013, 1046–49). As discussed below, the failure arises in this case because the rules governing the funding of different kinds of education and training discourage providers from meeting the needs of firms seeking to deploy new technologies. We can express this point slightly differently if we note that well-functioning innovation systems ensure that firms can gain access to the knowledge needed to deploy new technologies at commercial scale. Those stocks include the practical and theoretical knowledge possessed by various kinds of skilled worker, including technicians. If education and training providers do not offer the programmes needed to train technicians, then the innovation system can be said to have failed because it is not affording firms the amount, and blend, of practical and theoretical knowledge required to deploy new technologies to best effect (Smith 2000, 89–

90, 98–99; Borrás and Edquist 2019, 24–25, 29; cf. Metcalfe 2005, 68–69, Metcalfe 2007, 448–450).

3. System failure in vocational education and training in England: causes, cures and mitigation

This section explores several of the issues described above in greater detail through a discussion of the case of the English VET system. It begins by summarising some recent studies of the use, and acquisition, of technicians in various parts of advanced manufacturing in England, where employers are seeking to develop and deploy new technologies, in particular: advanced therapies; composites; industrial biotechnology; and the space industry (Lewis 2012a,b, Lewis 2013a, 2016b,b, Lewis 2020).[5] The evidence suggests, as we shall see, that England suffers from system failure of the kind described above.

3.1 Difficulties in recruitment and skill shortages

Many employers in these industries complain of difficulties in recruitment and skills shortages. Employers in industrial biotechnology and advanced therapies, many of whom are increasing both the scale and scope of their operations as they transition to full-scale commercial manufacturing, need to fill an increasing number of laboratory and manufacturing technician roles. However, they often struggle to recruit people with the relevant skills from the external labour market (Lewis 2016b, 34–35, Lewis 2020, 10–12). Employers in the 'upstream' part of the space industry find it hard to hire experienced, high-quality manufacturing technicians, hampering their efforts to expand (Lewis 2012b, 25–26, 34). Organisations in the aerospace and high-end automotive sectors that are looking to replace metallic with composite components find it difficult to recruit workers skilled at working with composite materials, hampering their capacity to deploy innovative, lightweight methods of production (Lewis 2012a: 22, 38, Lewis 2013a, 33–35). The consequence of such shortages for firms' capacity to utilise new technologies can be serious; as one report on the composites industry noted, 'There are examples of newly developed manufacturing kit in UK factories where they have no staff to run it' (Avalon Consultancy Services Limited 2012, 30; also see Sainsbury 2018, 3; HVMC and Gatsby 2020: 6, 38–39).

The shortages of technicians just described are consistent with evidence found by other studies, which consistently report sustained shortages of technician skills (UKCES 2015: 66–71; HM Government 2017, 37–38, 48; OECD 2017, 26–27; House of Lords 2018: 22, 25; Augar 2019: 25, 49–50). It is also noteworthy that England has a proportionately smaller number of apprentices in training, and a lower share of workers with intermediate-level skills, than its international competitors (Steedman 2010: 20, 26, 33–34; Augar 2019; Mason 2019, 8–10; Robinson and Dominguez-Reig 2020, 6–7, 26). Commentators have coined the phrase 'the missing middle' to refer to the way in which England has neglected the education and training of technicians (Field 2018; Augar 2019, 33–34).

One reason why such a small share of the workforce has intermediate-level skills relates to the topic of the next sub-section of this paper, namely the use of graduates to fill technician roles.

3.2 The use of over-qualified, but under-skilled, graduates to fill technician roles

Another significant finding concerns the way employers in certain sectors make extensive use of graduates to fill technician roles. Until recently, employers in advanced therapies and in industrial biotechnology filled the majority of their laboratory technician roles, and many manufacturing technician positions, by hiring graduates in chemical and biological science (Lewis 2016b, 17–20, 31–32, Lewis 2016a, 7–8). English universities produce large numbers of graduates in those disciplines, many of whom are willing to work as laboratory and manufacturing technicians. Believing that the graduates possessed the skills and knowledge needed to fill such roles, and faced with a paucity of applications from people with intermediate-level qualifications, it made sense for employers to recruit graduates to fill those roles (cf. Keep and James 2011, 59–60; Wolf 2015, 73–74; Mason 2012, 15–19, 27).[6] The graduates who filled them were overqualified in the sense that the level of formal qualifications they possess exceeds what is required to do the job effectively (Keep and Mayhew 2014, 11; Bessen 2016: 139–47; Lewis 2020, 9–10, 13). Again, these findings are consistent with those reported by other studies, which show that the use of over-qualified graduates is significant in the wider economy; between a quarter and a third of graduates occupy roles for which a degree is not required, a share that exceeds that found in most other European nations (Holmes and Mayhew 2015: 25–28; House of Lords 2018, 23–24).

However, studies also suggest that employers' expectations about the suitability of graduates for technician roles are often disappointed. First, employers have come to realise that graduates often lack the requisite practical skills. This illustrates what a recent study has referred to as a 'possibility which tends to get overlooked', by employers as well as academics, namely that 'graduates are less capable in some occupations than the nongraduates they are displacing' (Holmes and Mayhew 2015, 12). The reason is that the practical skills needed by people occupying technician roles are more readily acquired through work-based learning of the kind provided by apprenticeships than via the predominantly classroom-based instruction offered by universities 'so it's possible to be formally overqualified while still not being fully competent for a role' (UKCES 2015, 46). Second, employers also complain that graduates in technician roles often quickly become discontented, both with the highly routinised nature of technician work and also with the relatively low wages they are paid. As a result, they often leave relatively soon after joining their employer, raising labour turnover. This is particularly frustrating for employers who, having invested time and money in equipping over-qualified graduates with the practical skills needed by technicians, then see them depart before the firm can earn a satisfactory return on its investment (Lewis 2016b, 18–19, Lewis 2016a, 8–9).

3.3. The turn towards apprenticeships and response of education problems

The difficulties in recruiting technicians experienced by many innovative firms as they seek to expand their operations, coupled with employers' growing awareness of the shortcomings of over-qualified but under-skilled graduates, has prompted increasing numbers of employers to look towards apprenticeship training as a means of acquiring the skilled technicians they need to deploy their new technologies at commercial scale (Lewis 2012b, 26–27, Lewis 2013a, 37–42, Lewis 2016b: 32, 35–38, Lewis 2016a, 16).

An apprenticeship is a programme of learning, of at least a year in duration, that combines structured on-the-job training and productive work with part-time, formal technical education. The education and training are occupationally-oriented in the sense of being broad enough to enable their recipient to work in the relevant role – as a manufacturing technician, process operator, or maintenance engineer, say – in most if not all firms in their industry (rather than being narrowly focused on the specific needs of a particular firm). Successful completion of the apprenticeship usually results in the award of an externally-recognised qualification, pitched at the intermediate level (Ryan, Gospel, and Lewis 2007, 129). The range of skills and depth of theoretical knowledge acquired by apprentices implies that, once their training has been completed, they are well equipped to respond to the challenge of deploying new technology (Prais 1995; Tether et al. 2005: 6–7, 55–56; Toner 2011: 33–36, 45–48).[7]

Employers report that using apprenticeship training to acquire the technicians they need yields several benefits. First, it enables them to acquire skilled technicians in the face of shortages of skilled labour on the external labour market. Second, employers also observe that because apprentices spend a significant part of their training in the workplace, they acquire good practical skills and a realistic sense of what their job entails.[8] The increased take-up of apprenticeships helps to shed light on the issue – the need for more research on which has been widely acknowledged – of the balance employers seeking to deploy new technologies aim to strike between practical skills of the kind best acquired through apprenticeships and the largely theoretical knowledge acquired at university (Mason 2012: 25–27; Jones and Grimshaw 2016, 112; Toner and Woolley 2016, 328). The evidence summarised here indicates that on the margin employers seeking to deploy new technologies are placing more emphasis on practical skills or experience-based know-how – concerning how to apply knowledge in the workplace and corresponding to the DUI mode of innovation – and less on explicit theoretical knowledge of the kind that is integral to the STI mode of innovation (Jensen et al. 2007; also see Bessen 2015: 12–18, 42–46; Lund and Karlsen 2019, 9–10).

Third, employers laud the way that apprenticeship training enables them to give trainees a sound grasp of the standards to which work must be completed, something that is viewed as being especially important in industries – such as advanced therapies and space – where quality assurance procedures are especially rigorous. Finally, many employers noted that apprenticeship often served to build one value in particular, namely loyalty; by showing trainees that they are valued by their employer, who is willing to invest in their future, apprenticeship training can help to persuade young people that they have a promising future with the organisation and that they can develop their career without leaving it, thereby reducing labour turnover (Ryan, Gospel, and Lewis 2007, 2007, 140–41, 145–46; Lewis 2012b: 27, 31–32, Lewis 2013a, 43–44, Lewis 2016b: 36, 38, Lewis 2016a, 12–17).

3.4 Impediments to the use of apprenticeship training: The problem of the 'tyranny of small numbers'

However, many of the employers who have sought to use apprenticeships have faced significant problems in obtaining the education and training required by their apprentices. First, many have found it hard to persuade further education colleges to offer the requisite off-the-job technical education. For example, manufacturers that use composites have found it hard to find colleges willing to offer modules on that material as part of their engineering apprenticeship programmes, while employers in the space industry have struggled to persuade colleges to offer the courses needed by their apprentice manufacturing technicians. Second, industrial biotechnology and composites firms have struggled to obtain initial high-quality practical training for their apprentices. In some cases it has been impossible to find any provision within the relevant geographical area, as in the case of employers in the life sciences seeking training in cell cultivation under clean room conditions; in others, the training is available but only of low quality, being delivered in poor facilities by lecturers who are ignorant of current good practice (as often experienced by employers seeking to train technicians skilled in using composites) (Lewis 2012a, 31–32, Lewis 2012b, 31; Lewis 2013a: 46–47, Lewis 2016b, 39). Other reports have confirmed that employers seeking to train apprentices in STEM subjects often find it hard to obtain high-quality provision (Augar 2019, 26; House of Lords 2018, 74–75; HVMC and Gatsby 2020, 38).

The proximate cause of these difficulties lies in what has been called 'the tyranny of small numbers'. That term refers to way that the number of apprentices firms wish to train in a particular subject in the relevant geographical area is often too small to make it worthwhile for colleges and other providers to offer the relevant courses, given the high fixed cost of doing so and the prevailing funding regime. As a result, employers seeking to offer apprenticeships find it hard to persuade training providers to offer the relevant education and training programmes.[9] In the next section of the paper we shall argue that that the underlying cause of this problem lies in (the shortcomings of) the rules governing the funding of various kinds of education and training. That is to say, the problem is one manifestation of a 'system failure' in the English education system.

3.5 System failure in the English education system

The kinds of problems described above – shortages of technicians, the use of overqualified but under-skilled graduates to fill technician roles, and the difficulties organisation seeking to train apprentices often have in finding training providers – are symptomatic of a 'system failure' in the English education system. The underlying causes lies in the way that the rules governing the financing of education and training afford employers, providers and trainees insufficiently sharp incentives to develop the right mix of technician and graduate skills required to facilitate the deployment of new technologies. A recent government report summarised the situation as follows: 'There is a skills mismatch in the UK: despite the record numbers of the population with an undergraduate degree businesses are reporting a shortage of people with technical skills ... Rather than a need for more STEM graduates ... the greater shortages today appear to be for people with sub-degree qualifications ... there is an acute shortage of technician-level STEM skills' (House of Lords Economic Affairs Select Committee 2018: 15, 22; also see Mason 2019, 12–13; Sainsbury 2018, 3–4; Robinson and Dominguez-Reig 2020, 6–7, 18–19).

The underlying cause of this system failure lies in the rules governing the provision of various kinds of education and training. First, the rules governing public support lead to much more generous support being provided for universities offering full bachelors degrees than for the further education colleges in which intermediate-level qualifications are taught, while the rules governing the provision of financial support for students encourage young people to enter university to take a degree rather than opt for an apprenticeship. This has led to a systematic bias in favour of university education, as stated in a recent review of the English education system: 'At present, both on the supply and demand side, incentives are stacked in favour of the provision and take-up of three-year full-time undergraduate degrees and against the provision of [intermediate] level 4/5 courses ... [C]urrent arrangements set up an interconnected set of incentives which result in young people opting for full time degrees (level 6) and in institutions marketing and supplying full degrees at maximum price to the near-exclusion of other options' (Augar 2019: 35, 37; also see House of Lords

Economic Affairs Select Committee 2018, 9–10, 39–41, 45–53; Sainsbury 2018, 6–7; Mason 2019: 3, 8, 35–36).

Second, this bias against technician training has been compounded by the way that funding rules discourage apprenticeship providers from offering intermediate-level apprenticeships in science and engineering. Declining capital funding has prevented FE colleges from investing in the facilities – the training workshops and up-to-date equipment – and the tutors conversant with current industry best practice needed to teach such apprenticeships. Moreover, the funding rules imply that longer, intermediate-level apprenticeships in STEM subjects have smaller profit-margins than shorter, lower-level apprenticeships in subjects such as customer service and business administration. Additionally, the higher-level apprenticeships are harder to pass than the lower-level ones, and so riskier for providers under the current 'output-related' funding regime. The upshot is that it is both less remunerative and riskier for providers to offer the longer, intermediate-level STEM apprenticeships (Wolf 2015: 5–6, 9–12; Augar 2019: 122–30, 149–50; Mason 2019, 16–18).

Funding rules thus "drive providers away from higher technical provision' (Augar 2019, 37). The problem is especially pronounced in the case of the apprenticeships required by firms seeking to deploy new technologies, the provision of which may require providers to incur significant fixed costs as they invest in new training facilities and tutors:

> Developing new courses is always risky, especially if they require large amounts of equipment or the hiring of very specialist staff; given current conditions, launching new high-cost provision at level 4 or 5 is additionally risky and financially unattractive. (Augar 2019: 37.)

The consequence is that providers face only weak incentives to offer the apprenticeship training needed by employers in advanced manufacturing. As summarised by one recent report, 'The heavy bias in public spending ... towards higher education at the expense of further education and vocational education and training' has 'restricted[ed] development of intermediate skills ... and thus contribute[d] to poor productivity performance in the workplace' (Mason 2019, 3; also see Augar 2019: 9, 25).

The result of these problems is a systemic failure to align workforce development and technology development that manifests itself, as described above, in employers experiencing shortages of skilled technicians, in the use of overqualified but under-skilled graduates in technician roles, and in a reluctance on the part of education and training providers to support employers' efforts to train apprentices. Ultimately, dealing with such problems requires significant reform of those rules, as set out in the recent Augar Review (Augar 2019; also see House of Lords 2018: 42–53 and Mason 2019, 36–45). Rather than rehearsing those arguments here, however, we turn instead to a concrete example of how matters can be improved even within the current overarching set of rules (not least because, at the time of writing, it is uncertain whether any of the Augar Review's recommendations will be implemented by policy makers).[10]

4. Institutional entrepreneurship to develop technician skills the case of advanced therapies

While the system-level, or social structural influence, on innovation is important, this does not mean that organisations such as firms are entirely deprived of the power of agency (understand as capacity to change, at least to some extent, the outcomes produced by the system). Institutions matter, facilitating and constraining the activities undertaken by the organisations within the system (Lewis 2000; Sotarauta and Pulkkinen 2011, 105–08; Miörner and Trippl 2017: 483; Lund and Karlsen 2019, 5). But they do not entirely determine how those actors behave, leaving open the possibility of creative responses that can change the outcomes produced by the system (Edquist 1997b: 17–18; Edquist and Johnson 1997, 59–60; Lewis 2000). In particular, notwithstanding the impediments to the development of an adequate technician workforce described above, firms have sometimes been able to act in ways that see them overcome the tyranny of small numbers and thereby persuade VET providers to develop the technician training programmes they needed to deploy new technologies at scale (Lund and Karlsen 2019, 5–6; Borrás and Edquist 2019, 22–24).

An example comes from the English advanced therapies (AT) industry, a branch of medicine centring on the replacement or regeneration of human cells, tissues or organs in order to restore people's health. AT relies on novel technologies, which have only very recently begun to deployed at commercial scale (Cell and Gene Therapy Catapult 2016: 8–10; Lewis 2016a). As firms sought to move to full-scale manufacturing, they realised that they needed to train apprentices in order to fill the increasing number of manufacturing technician roles they would be creating. The Advanced Therapies Manufacturing Taskforce, an industry-led group established to promote the commercialisation of AT in the UK, responded to this emerging need by securing funding from the UK government, under the auspices of its Industrial Challenge Strategy Fund, to finance the creation of a bespoke apprenticeship training scheme (Lewis 2020).

The scheme has a number of distinctive features which have helped to make it financially viable even in the face of the 'tyranny of small numbers'. First, it is located in London, at the heart of a concentration of expanding AT firms, helping to ensure that the 'critical mass' of apprentices needed to overcome the 'tyranny of small numbers' was achieved. Second, the off-the-job technical education, which sees apprentices studying for intermediate-level qualifications in bioscience-related subjects, was provided by distance learning, so that the programme was also accessible to firms located elsewhere in England, further increasing demand. Third, some of the specialist practical training such as cell cultivation under clean room conditions, was provided using existing facilities – in particular, clean rooms located at the Cell and Gene Therapy Catapult Centre (CGTCC) in London – so that the cost of creating new ones was avoided. These features of the scheme have helped to ensure its financial viability. What we can see here, then, are the firms within an emerging industry working together, and with other organisations, in order to ensure that they demand a critical mass of apprentices and thereby overcome the problem posed by the tyranny of small numbers.[11]

It is worth elaborating briefly on the contribution made by CGTCC, because – aside from some of its facilities being used for the provision of specialist training – it also played another, fundamental role in role in the creation of the new apprenticeship, in particular by facilitating the process of knowledge systematisation through which the programme's educational content was determined. Catapult Centres are organisations whose goal is to promote the commercialisation of new technology by reducing the risk associated with that endeavour. They do so by providing facilities and expertise that help firms to demonstrate that ideas that have been shown to work when deployed at small-scale, in the university laboratory or workshop, also work at the larger scales involved in commercial manufacturing. By doing so, the Catapults reduce the risks associated with the development of new technologies, thereby catalysing innovation (Hauser 2014).

This is significant because, thanks to their role in helping to commercialise new technologies, Catapult Centres are well acquainted with emerging manufacturing processes and are therefore in a good position to collect information about the skills and knowledge needed to put them into practice (i.e. to contribute to knowledge systematisation). The CGTCC exploited this opportunity to engage in 'knowledge collection' (Rupietta and Backes-Gellner 2019, 573–74) by using funding from the Gatsby Foundation to create an 'expert educator' (EE) team, consisting of a small group of technologists and educators who gathered information from employers about the skills and knowledge needed to use the technologies in question (cf. Bonvillian and Singer 2017: 235–36; HVMC and Gatsby 2020: 30, 62–63). The team then worked with education and training providers to use that information to create a formal training programme for apprentice manufacturing technicians, in line with the relevant occupational standards ('collective knowledge synthesis' [cf. Rupietta and Backes-Gellner 2019: 574]). Twenty-nine apprentices, drawn from 11 AT companies, began training in 2018. This grew to 100 apprentices, from 32 employers, in September 2020.[12] The training of these apprentices thus facilitates a process of 'knowledge transfer' and 'knowledge application' as AT firms acquire the skilled and knowledgeable workers needed for full-scale manufacturing (cf. Rupietta and Backes-Gellner 2019, 574–75). The scheme has been described by the UK Government's as an example of 'what works' in policy-making and as an 'investment [that] is already paying off – as these skillsets and techniques are capitalised in the pursuit of vaccines' (HM Government 2020, 21).[13]

The EE team can thus be seen to have facilitated the process of knowledge systematisation, bringing employers and VET providers together to engage in a process of mutual learning through which the content of the apprenticeship programme was determined. In doing so, the CGTC forms part of what Stan Metcalfe has felicitously referred to as the 'innovation infrastructure', namely the set of organisations that 'coordinate access to complementary kinds of knowledge required to innovate' (Metcalfe 2005, 66). In this case, the CGTCC used its EE team to help firms and education and training providers work together both to identify the skills and training programmes required to support new technologies and also to ensure that the financial viability of the programmes in question.[14] Put slightly differently, the CGTCC acted as a 'network integrator', connecting the industrial and education systems so as to help firms to acquire the skilled technicians they need (Kochan, Finegold, and Osterman 2012; also see Sainsbury 2020, 1062). The broader significance of this example can be seen if we recall the following remark from an insightful article on innovation policy: 'A key issue arising from systems approaches is the need to identify and perhaps support nodal points in the [knowledge] creation and distribution systems . . . to identify key points or functions within the system where public support would improve the overall distribution capacity' (Smith 2000, 99). The CGTCC is a case in point, where a relatively small amount of external funding facilitated the creation of an EE team that significantly increased the capacity of the system to create and distribute knowledge about the technician skills needed to manufacture AT at commercial scale, thereby helping to coordinate technology development and workforce development.[15]

The CGTCC is, however, unusual amongst the Catapult Centres in being engaged with apprenticeship training. Only two other Catapults – the Advanced Manufacturing Research Centre, which focuses on the development of new machining techniques, and the Manufacturing Technology Centre, which helps to develop innovative manufacturing technologies – have played a significant role in promoting apprenticeship training to support emerging technologies (Lewis 2019, 28; Perkins 2019, 52–53). This is because skills development does not feature in the indicators by reference to which the Catapults' performance is judged. As a recent report has stated, workforce development, especially at the technician level, has "not always been seen as part of the [Catapults'] core businesses or been able to be pursued with a clear mandate and . . . with sponsoring department investment" (HVMC and Gatsby 2020, 17). Yet is also true that if firms seeking to develop and deploy new technologies cannot obtain the requisite technicians, then the Catapults' efforts to develop those technologies will be in vain. Hence the report's conclusion that the Catapults, and other centres of innovation, 'should make a more systematic contribution to the knowledge and skills needs of the future manufacturing workforce, aligning its capability to future manufacturing technologies at all levels and ages' (HVMC and Gatsby 2020, 17; also Lewis 2019, 26–30). Workforce development therefore needs to become an explicit part of the Catapults' remit, with a budget for doing so and with assessments of the Catapults' performance taking into account their achievements in developing technician skills, so that workforce development is placed on a par with technology development in their priorities (Perkins 2019, 53). Only then will these organisations bridge the gap or structural hole between the industrial and educational (sub-)systems and thereby connect and align workforce development and technology development.[16]

The creation of an EE team within the CGTCC highlights the importance of a second kind of agency, aside from that exercised by firms as they strive to develop and deploy new technologies. This is 'system-level agency', a term that refers to the efforts of organisations acting at the level of the system to create the (social-structural) conditions in which firms are able to exercise their agency fruitfully and bring their plans to a successful conclusion (Isaksen et al. 2019, 50–53; Lund and Karlsen 2019: 6, 12–14). The creation of an EE team was an act of institutional entrepreneurship (Sotarauta and Pulkkinen 2011; Miörner and Trippl 2017: 485, 489, 492) that enabled the CGTCC to act as a bridge between firms seeking to train apprentices and education providers, enabling them to co-create training programmes that would satisfy the emerging need for technicians in ATs (Karlsen et al. 2012, 125–26, 134). This change in the institutional architecture of the innovation system made it possible to articulate and transmit firms' knowledge of the demands new technologies make upon technicians to training providers and to translate it into training syllabi, and associated jobs descriptions and statements of competence, thereby helping those providers to learn how to adapt their offerings appropriately. In this way, the creation of the EE team helped firms to acquire the skilled technicians they need deploy their new technology, thereby facilitating successful firm-level agency.[17]

5. Conclusion

The analysis presented above makes a theoretical contribution by showing how it is possible to incorporate the role of technicians, and of VET providers, within the IS framework, thereby contributing to recent efforts to fill a notable gap in the IS literature. Technicians contribute both to incremental innovation and to firms' absorptive capacity. If providers are to contribute fully to technology diffusion, then there needs to be an institutional architecture that will facilitate the 'knowledge systematisation' required for training programmes to be developed and/or updated appropriately. However, where the rules governing the provision of education and training are inappropriate, or the organisations needed to facilitate knowledge systematisation are absent or deficient, system failures can arise.

If that is the case, then a country's education system will fail to develop the workforce necessary to facilitate the effective deployment of new technology.

England is a case in point, with the 'missing middle' - the deficit of intermediate-level skills – reflecting a system failure caused by a deficient institutional architecture. The education and training required to equip workers with the intermediate-level skills and knowledge needed to support the deployment of new technology is typically transferable, in the sense of being useful to several employers, and is therefore worthy of government support to cover some of the relevant costs. However, as the Augar Review has made clear, the rules governing the provision of financial support for training do not generate the incentives needed to encourage the creation of a suitable technician workforce. What is required, as one recent report has put it, are reforms that will change the pattern of incentives so as to mitigate the system failure currently exhibited by the English VET system and to put in place an institutional architecture that will 'promote connectivity between the … [country's] innovation and skills systems' and thereby ensure that 'workforce talents and skills … become more aligned with technology and productivity opportunities' (HVMC and Gatsby 2020, 9; also see Sainsbury 2020, 1062). This paper has also explored what this institutional architecture might involve. Through its discussion of the importance of centres of innovation like the Catapults and of EE teams, the paper has examined the kinds of organisations and institutions needed to align the development of human and physical capital, in particular at the technician level, so innovative firms can acquire the skilled workforce they need.[18]

Taking seriously technicians' and VET providers' contribution to innovation would encourage policy-makers to reorient their attention, which has tended to focus on R&D undertaken by highly qualified research scientists and engineers, towards the need to ensure that employers have timely access to the intermediate-level skills required to deploy new technologies at commercial scale. As one recent contribution has rightly put it,

> While investing in HRST [human resources for science and technology, i.e., very highly qualified research scientists and engineers] and leading-edge scientific and engineering endeavours are undoubtedly critical for productivity and economic growth, policies with a narrow HRST focus risk generating a deficit in the stock of essential technical and intermediate-level skills and knowledge" (Jones and Grimshaw 2016, 109; also see Borrás and Edquist 2019: 2.).

Policy-makers' failure in the past to do justice to the importance of technician skills and training arguably reflects the continued influence of the old, linear view of innovation, which emphasises the importance of high-level scientific research and neglects the importance of other influences on the development and diffusion of new technologies, including those associated with the work of technicians (Jensen et al. 2007, 690; Edquist 2014;

Toner and Woolley 2016: 322, 324, 327, 336; also see Toner and Dalitz 2012).

Paying heed to the contribution made by technicians and VET would encourage and inform a more holistic approach to innovation policy that – contrary to the linear, science-centric perspective – would recognise the complex, non-linear nature of innovation. Such an approach is more likely to recognise and do justice to the complex interdependencies between skills, education and innovation and thereby to lead to policies that promote, rather than hamper, the development of the skills needed for the widespread diffusion of new technologies (Borrás and Edquist 2019; Vorley and Nelles 2019).

There is also significant scope for scholars working within the IS tradition to contribute to the growing literature on the relations between technician skills, VET and innovation. Additional case studies examining whether, and if so how, knowledge systematisation is carried out are needed. Also, the question arises of whether other nations suffer from system failures of the kind experienced in England. In addition to studies of the development of technicians skills for relatively new industries, like AT, it would also be important to investigate how more established industries are seeking to meet the challenge of retraining their existing technician workforce so that they can make good use of new technologies (e.g. related to digital manufacturing). In these and other ways, it should be possible to continue to fill the gap in the IS literature on the topic of technicians, VET providers and innovation.

Notes

1. Technician roles, which require at least an additional year of post-school education and training, are also known as 'middle-skilled' roles (Kochan, Finegold, and Osterman 2012; MIT Open Learning 2020, 7) or 'skilled technical' roles (NASEM 2017, 13–14).
2. This distinction parallels that between 'exploration', understood as the search for new technologies and 'exploitation', centrally involving the application and refinement of known technologies, drawn by March (1991).
3. As noted above, technicians are most likely to contribute to employers' realised absorptive capacity; but involvement in apprenticeship training may add to firms' potential absorptive capacity if apprentices receiving up-to-date training alert their employer to technologies of which they were previously unaware.
4. For example, deficiencies in the technician workforce have in the past caused British automotive and engineering firms to be slow in deploying new technology, retarding innovation and reducing productivity and competitiveness (Prais 1995; Mason and Wagner 2005).
5. The chosen industries and technologies have all been identified as having the potential to develop and deploy new technologies in ways that will bring significant benefits in terms of productivity, growth and exports (DBIS 2014; HM Government 2017).
6. The same is also true of employers in other, more established parts of the economy, such as the chemical industry and the university sector, where many laboratory

technician positions are filled by graduates (Lewis 2013b, 15–17; Lewis and Gospel 2015, 10–11).

7. Given that in the case of some important technologies, such as those associated with industry 4.0, it will be necessary to augment the skills of the incumbent workforce as well as to train new recruits, it is important that training be offered in the form of discrete, credit-bearing modules that established workers can use to upgrade their existing skills (HVMC and Gatsby 2020, 36–37, 39 48).
8. The superiority of work-based learning over classroom-based instruction for equipping apprentices with practical skills of the kind valued by employers has also been noted by OCED (2015: 7), Mason (2019, 13), and Robinson and Dominguez-Reig (2020, 27).
9. One might even argue that there is a skills 'valley of death', analogous to the technology 'valley of death' that bedevils efforts to commercialise new technologies. The term 'valley of death' is commonly used to denote the difficulties faced by firms seeking to turn ideas obtained through promising research into commercially-viable products. Such firms often struggle to obtain the finance needed for commercialisation, due to the reluctance of private funders to support risky ventures about whose commercial viability there remains considerable uncertainty (McKinsey Global Institute 2012, 135–36; Edler and Fagerberg 2017, 17). Similar difficulties hamper the provision of training for emerging technologies, with providers being reluctant to incur the significant fixed costs associated with offering the relevant training because, especially early in the adoption process, there may be significant uncertainty about the diffusion of the technology and therefore also about the demand for training, leading to reluctance to offer the programmes until the demand is well established (cf. Bessen 20,915: 65–67).
10. This analysis of the problems facing the UK education and training system as stemming from the institutional framework governing the provision of different kinds of education and training is of course quite consistent with the broader literature on that topic, which demonstrates the importance of national institutional frameworks in shaping different countries' performance in the field of vocational education and training. See, for just a few examples from a large literature, Culpepper (2003), Wolter and Ryan (2011), Goergen et al. (2012), and Bosch (2018). For a discussion of similar problems in the case of the USA, see Bessen (2015: 147–49) and MIT Open Learning (2020, 8–19).
11. While data on the cost per apprentice of this training were not available, the programme has several features in common with other apprenticeships, in engineering and construction, where studies indicate that employers make a substantial investment in their apprentices, above and beyond any government funding. These features include the length and high level of the apprenticeship along with the fact that trainees spend a substantial amount of time learning off the job, at college, rather than undertaking productive work (Hogarth and Hasluck 2003; Ryan, Gospel, and Lewis 2006, 379; Gambin and Hogarth 2017). The willingness of AT employers to make this net investment reflects the returns they expect to earn from having the skilled manufacturing technicians they need to move towards full-scale manufacturing.

    It is also noteworthy in this context that both the practical skills in cell cultivation under clean room conditions that apprentices will learn during this training programme, and the underpinning knowledge in cell biology and microbiology they will acquire in the college-based portion of their training, are highly transferable, being useful – employers noted – not only to firms in the AT industry but also to employers in the life sciences sector more broadly (e.g. in the pharmaceuticals industry). If labour markets are imperfectly competitive, then some of the benefits generated by those skills will be enjoyed by firms that did not contribute to their creation, a positive externality whose existence justifies government financial support for the training (Stevens 1999, 19–23; Hogarth and Gambin 2017, 660–61). However, the support in question should be only partial because, as noted in Section 2.1 above, firms that equip their workers with transferable skills are likely to earn a positive private return on their investment in training (albeit less than the full social return). The degree of government support should arguably be less for employers who are seeking to retrain an existing workforce, for two reasons: (i) first, because the amount of training would be less in this case than in training apprentices, who are initially unskilled and so – unlike the incumbent workers – possess none of the relevant skills; and (ii) second, because the incumbent workers are likely already to have built up a degree of loyalty to their employer and are therefore less likely to move elsewhere before the employer has earned a satisfactory return on its investment in training (i.e. the size of the external problem is likely to be smaller in the case of incumbent workers than with new apprentices). It is interesting to note in this context the results of an evaluation of the Employment Training Panel, a Californian initiative designed to provide funding for the training of incumbent workers (including for, but not restricted to, the use of new technology). The evaluation found that the programme had beneficial effects the company performance (SPR 2020).

12. See CGTCC (2020, 8) and https://www.linkedin.com/feed/update/urn:li:share:6709371946905178113.
13. Lund and Karlsen (2019, 10–15) insightfully discuss a slightly different example, involving firms and VET providers in Norway collaborating to create training programmes to equip technicians with the skills required to deploy new digital manufacturing technologies.
14. To use slightly different terminology, the CGTC can be said to help constitute the economy's 'public knowledge infrastructure', namely the set of organisations engaged in the production, distribution and management of the background knowledge – in this case concerning the skills and knowledge required by the technician workforce – that facilitates innovative production (David and Wright 1997, 223–24).
15. Members of the EE team also played a second important role, by helping the employers – most of whom were relatively small firms unfamiliar with apprenticeships – cope with the administrative requirements of the training programme. This included helping firms to recruit apprentices, to manage their training so that the requirements of programme were satisfied, and to navigatie the system through which government financial support was provided. In this way, the EE team alleviated much of the administrative burden associated with taking apprentices, facilitating firms' involvement in the apprenticeship scheme (cf. Lewis 2014, 505; Bonvillian and Singer 2017: 230–31).
16. It is also worth noting that the situation in the AT industry, which is a relatively new industry with a very small number of established technician-level workers, implies that there is relatively little need for AT firms to (re)train an existing or incumbent technician workforce. The challenge facing AT firms, as explained above, is to fill the relatively large number of technician-level roles being created as firms expand the scale and scope of their activities by moving from a focus on R&D and process development to full-scale commercial manufacturing. The situation is rather different in more established industries, where the need to deploy new technologies at scale will require the (re)training of a large incumbent technician workforce. Perhaps the most significant example can be found in advanced manufacturing, where the advent of so-called industry 4.0 is creating the need to equip a large incumbent workforce with new 'digital' skills (HVMC and Gatsby 2020: 11, 26–27, 46,

48). In this case, as in the case of AT, Catapult Centres – such as the Manufacturing Technology Research Centre – arguably have an important role to play in identifying the relevant skills and knowledge and devising associated training programmes. But what is different in the case of digital manufacturing is that the training programmes in question must cater to the needs of established workers, who already possess significant skills and knowledge, as well as to the needs of apprentices. Hence the importance, briefly mentioned in footnote 7 above, of these programmes being modular; if they are broken down into discrete, credit-bearing units, then established workers can take only those units needed to upgrade their existing skills, whilst apprentices can of course take the whole suite of units in order to become fully trained (HVMC and Gatsby 2020, 36–37, 39 48). It is also worth noting in this context that the prospect of at least some modules being taken by large numbers of established workers will, by increasing demand for the training in question, help to overcome the 'tyranny of small numbers' that (as we have seen) hampers the provision of high-quality training in advanced manufacturing in all too many sectors of UK industry (Lewis 2016b: 5, 44, 50, Lewis 2016a, 24).

17. Similarly, the change in the rules governing how the Catapults' performance is assessed in order to encourage more of them to engage wholeheartedly in workforce development requires an act of institutional or public entrepreneurship (Ostrom 1990: 127) by creative policy-makers, who wish to ensure that the Catapults fulfil their potential to act as bridges between the industrial and education systems.
18. This theme has been echoed by two recent commentators on American innovation policy, according to whom 'education and training programmes should not be a sideline but rather a key part of the technology development and dissemination effort' (Bonvillian and Singer 2017, 225). In the US case the proposal is that the Manufacturing Institutes, the American equivalent of the UK's Catapult Centres, should play a key role in 'knowledge systematisation' along the lines outlined in the previous section of this paper (MIT Open Learning 2020, 8–19).

Acknowledgements

I am very grateful to Bill Bonvillian, Ewart Keep, Ken Mayhew, and Alison Wolf for helpful comments on, and discussions about, earlier versions of this paper. Two anonymous referees also provided useful comments. I am grateful also to the F. A. Hayek Programme, based at the Mercatus Centre at George Mason University, for financial assistance, provided under the auspices of its Work and Dependency project.

Disclosure statement

No potential conflict of interest was reported by the author.

References

Amendola, M., and F. Vona. 2012. "Coordinating the Accumulation of Physical and Human Capital in Different Institutional Settings." *Economics of Innovation & New Technology* 21 (7): 631–653. doi:10.1080/10438599.2011.633831.

Augar, P. 2019. *Review of Post-18 Education and Funding*. Cp117. London: Her Majesty's Stationary Office.

Avalon Consultancy Services Limited. 2012. *Lessons Learned from Development and Implementation of a Composites Strategy in the UK*.

Bessen, J. 2015. *Learning by Doing: The Real Connection Between Innovation, Wages and Wealth*. New Hsven: Yale Univerity Press.

BIS2011. "Innovation and Research Strategy for Growth." *BIS Economics Paper No* 15: London. Department for Business, Innovation and Skills.

Bonvillian, W., and P. Singer. 2017. *Advanced Manufacturing: The New American Innovation Policies*. Cambridge, MA: MIT Press.

Borras, S., and C. Edquist. 2015. "Education, Training and Skills in Innovation Policy." *Science & public policy* 42 (2): 215–227.

Borrás, S., and C. Edquist. 2019. *Holistic Innovation Policy*. Oxford: Oxford University Press.

Bosch, G. 2018. "Different National Skills Systems." In *The Oxford Handbook of Skills and Training*, edited by C. Warhurst, K. Mayhew, D. Finegold, and J. Buchanan, 424–43. Oxford: Oxford University Press.

Breda, M., and P. Del Rio. 2013. "The Market Failure and the Systemic Failure Rationales in Technological Innovation Systems." *Research Policy* 42 (5): 1039–1052. doi:10.1016/j.respol.2013.02.008.

Brunet Iscart, I., and J. Rodríguez-Soler. 2017. "The VET System and Industrial SMEs: The Role of Employees with VET Qualifications in Innovation Processes." *Journal of Vocational Education & Training* 69 (4): 599–616. doi:10.1080/13636820.2017.1322130.

Cell and Gene Therapy Catapult. 2016. *Cell and Gene Therapy Manufacturing in the UK: Capability and Capacity Analysis March 2016*. London: Cell and Gene Therapy Catapult.

CGTCC 2020. *Cell and Gene Therapy Catapult Centre Annual Review 2020*. Available online at https://fr.zone-secure.net/-/Catapult_CGT_Annual_Review_2020/-/#page=8

Chaminade, C., and C. Edquist. 2010. "Rationales for Public Policy Intervention in the Innovation Process: Systems of Innovation Approach." In *Innovation Policy: Theory and Practice. An International Handbook*, edited by R. Smits, S. Kuhlman, and P. Shapira. London: Edward Elgar.

Cohen, W., and D. Levinthal. 1990. "Absorptive Capacity: A New Perspective on Learning and Innovation." *Administrative Science Quarterly* 35 (1): 128–152. doi:10.2307/2393553.

Crafts, N., and A. Hughes 2013. *Industrial Policy for the Medium to Long-term*. Future of Manufacturing Project: Evidence Paper 37. London: Foresight, Government Office for Science.

Culpepper, P. 2003. *Creating Cooperation: How States Develop Human Capital in Europe*. Ithaca: Cornell University Press.

David, P., and G. Wright. 1997. "Increasing Returns and the Genesis of American Resource Abundance." *Industrial and Corporate Change* 6 (2): 203–245. doi:10.1093/icc/6.2.203.

DBIS. 2014. *The Case for Public Support of Innovation: At the Sector, Technology and Challenge Area Levels*. London: Department of Business, Innovation and Skills.

Dosi, G., C. Freeman, R. Nelson, G. Silverberg, and L. Soete. 1988. *Technical Change and Economic Theory*. eds ed. London: Pinter Publishers.

Edler, J., and J. Fagerberg. 2017. "Innovation Policy: What, Why, and How." *Oxford Review of Economic Policy* 33 (1): 2–23. doi:10.1093/oxrep/grx001.

Edquist, C., ed. 1997a. *Systems of Innovation: Technologies, Institutions*. London and Washington: Pinter.

Edquist, C. 1997b. "Systems of Innovation Approaches – Their Emergence and Characteristics." In *Systems of Innovation: Technologies, Institutions*, edited by C. Edquist, 1–35. London and Washington: Pinter.

Edquist, C. 2014. "Striving Towards a Holistic Innovation Policy in European Countries – but Linearity Still Persists." *STI Policy Review* 5: 1–19.

Edquist, C., and B. Johnson. 1997. "Institutions and Organisations in Systems of Innovation Approaches." In *Systems of Innovation: Technologies, Institutions*, edited by C. Edquist, 41–63. London and Washington: Pinter.

Fagerberg, J. 2017. "Innovation Policy: Rationales, Lessons and Challenges." *Journal of Economic Surveys* 31 (2): 497–512. doi:10.1111/joes.12164.

Felstead, A., D. Gallie, F. Green, and G. Henseke. 2020. "Getting the Measure of Employee-Driven Innovation and Its Workplace Correlates." *British Journal of Industrial Relations* 58 (4): 904–935. doi:10.1111/bjir.12528. Accessed 4th April 2020.

Field, S. 2018. *The Missing Middle: Higher Technical Education in England*. London: The Gatsby Foundation.

Gambin, L., and T. Hogarth. 2017. "Employers and Apprenticeships in England: Costs, Risks and Policy Reforms." *Empirical Research in Vocational Education and Training* 9 (1). doi:10.1186/s40461-017-0060-5.

Goergen, M., C. Brewster, G. Wood, and A. Wilkinson. 2012. "Varieties of Capitalism and Investments in Human Capital." *Industrial Relations: A Journal of Economy & Society* 51: 501–527. doi:10.1111/j.1468-232X.2012.00688.x.

Gonon, P., and M. Maurer. 2012. "Educational Policy Actors as Stakeholders in the Development of the Collective Skill System: The Case of Switzerland." In *The Political Economy of Collective Skill Formation*, edited by M. Busemeyer and C. Trampusch, 126–49. Cambridge: Cambridge University Press.

Hauser, H. 2014. *Review of the Catapult Network*. London: Department of Business, Innovation and Skills.

HM Government 2017. *Building Our Industrial Strategy: Green Paper*. London: London: Department of Business, Innovation and Skills.

HM Government. 2020. *UK Research and Development Roadmap*. London: Crown Copyright.

Hogarth, T., and L. Gambin. 2017. "Who Pays for Skills? Differing Perspectives on Who Should Pay and Why." In *The Oxford Handbook of Skills and Training*, edited by C. Warhurst, K. Mayhew, D. Finegold, and J. Buchanan, 652–70. Oxford: Oxford University Press.

Hogarth, T., and C. Hasluck. 2003. "Net Costs of Modern Apprenticeship Training to Employers." In *Research Report*. Vol. 418. (London, DfES).

Holmes, C., and K. Mayhew. 2015. *Over-Qualification and Skills Mismatch in the Graduate Labour Market*. London: CIPD.

House of Lords Economic Affairs Select Committee. 2018. *Treating Students Fairly: The Economics of Post-School Education*. London: House of Lords.

HVMC and Gatsby. 2020. *Manufacturing the Future Workforce*. Solihull: The High Value Manufacturing Catapult Centre and the Gatsby Foundation.

Isaksen, A., S.E. Jakobsen, R. Njøs, and R. Normann. 2019. "Regional Industrial Restructuring Resulting from Individual and System Agency." *Innovation: The European Journal of Social Science Research* 32 (1): 48–65. doi:10.1080/13511610.2018.1496322.

Jensen, M. B., B. Johnson, E. Lorenz, and B. A. Lundvall. 2007. "Forms of Knowledge and Modes of Innovation." *Research Policy* 36 (5): 680–693. doi:10.1016/j.respol.2007.01.006.

Jones, B., and D. Grimshaw. 2016. "The Impact of Skill Formation Policies on Innovation." In *Handbook of Innovation Policy Impact*, edited by J. Edler, P. Cunningham, A. Gok, and P. Shapira. Cheltenahm: Edward Elgar.

Karlsen, J., M. Larrea, J. Wilson, and M. Aranguren. 2012. "Bridging the Gap Between Academic Research and Regional Development in the Basque Country." *European Journal of Education* 47: 122–138. doi:10.1111/j.1465-3435.2011.01512.x.

Keep, E., and S. James. 2011. "Employer Demand for Apprenticeships." In *Rethinking Apprenticeships*, edited by T. Dolphin and T. Lamming, 55–65. London: IPPR.

Keep, E., and K. Mayhew. 2014. *Industrial Strategy and the Future of Skills Policy: The High Road to Sustainable Growth*. London: CIPD.
Kochan, T., D. Finegold, and P. Osterman2012. "Who Can Fix the 'Middle-Skills' Gap?". *Harvard Business Review*December. 80(6): 2076–2088. 10.1128/IAI.00149-12.
Lewis, P. 2000. "Realism, Causality and the Problem of Social Structure." *Journal for the Theory of Social Behaviour* 30 (3): 249–268. doi:10.1111/1468-5914.00129.
Lewis, P. 2012a. *Flying High: A Study of Technician Skills and Training in the UK Aerospace Industry*. London: Gatsby Foundation.
Lewis, P. 2012b. *Space for Technicians? An Analysis of Technician Skills and Training in the UK Space Sector*. London: The Gatsby Foundation.
Lewis, P. 2013a. *Skills and Training for Composites Manufacturing and Use in the UK: An Analysis*. London: Gatsby Foundation.
Lewis, P. 2013b. *Technician Roles, Skills and Training in the UK Chemical Industry: An Analysis*. London: Gatsby Foundation.
Lewis, P. 2014. "The Over-Training of Apprentices by Employers in Advanced Manufacturing: A Theoretical and Policy Analysis." *Human Resource Management Journal* 24 (4): 496–513. doi:10.1111/1748-8583.12039.
Lewis, P. 2016a. *How to Create Skills for an Emerging Industry: The Case of Technician Skills and Training in Cell Therapy*. London: Gatsby Foundation.
Lewis, P. 2016b. *Technician Roles, Skills and Training in Industrial Biotechnology: An Analysis*. London: Gatsby Foundation.
Lewis, P. 2019. *Technicians and Innovation*. London: Gatsby Foundation.
Lewis, P. 2020. "Developing Technician Skills for Innovative Industries: Theory, Evidence from the UK Life Sciences Industry, and Policy Implications." *British Journal of Industrial Relations* 58 (3): 617–643. doi:10.1111/bjir.12532.
Lewis, P., and H. Gospel. 2015. "Technicians Under the Microscope: The Training and Skills of University Laboratory and Engineering Workshop Technicians." *Journal of Vocational Education & Training* 67 (4): 421–444. doi:10.1080/13636820.2015.1076502.
Lund, H., and A. Karlsen. 2019. 'The Importance of Vocational Education Institutions in Manufacturing Regions: Adding Content to a Broad Definition of Regional Innovation Systems.'. *Industry and Innovation*, online first, 27(6): 660–679. 10.1080/13662716.2019.1616534.
Lundvall, B.-A., ed. 1992. *National Innovation Systems: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.
Lundvall, B- A. 2007. "National Innovation Systems—Analytical Concept and Development Tool." *Industry & Innovation* 14 (1): 95–119. doi:10.1080/13662710601130863.
Lundvall, B.-Å., and B. Johnson. 1994. "The Learning Economy." *Journal of Industry Studies* 1 (2): 23–42. doi:10.1080/13662719400000002.
Makkonen, T., and B. Lin. 2012. "Continuing Vocational Training and Innovation in Europe." *International Journal of Innovation and Learning* 11 (4): 325–338. doi:10.1504/IJIL.2012.047135.
March, J. 1991. "Exploration and Exploitation in Organizational Learning." *Organization Science* 2 (1): 71–87. doi:10.1287/orsc.2.1.71.
Mason, G. 2012. *Science, Engineering, and Technology (SET) Technicians in the UK Economy*. London: Gatsby Foundation.
Mason, G.2019. "Higher Education, Initial Vocational Education and Training and Continuing Education and Training: Where Should the Balance Lie?". *LLAKES Research Paper* 66: London: LLAKES.
Mason, G., A. Rincon-Aznar, and F. Venturini. 2019. "Which Skills Contribute Most to Absorptive Capacity, Innovation, and Productivity Performance? Evidence from the US

and Western Europe." *Economics of Innovation & New Technology* 29 (3): 223–241. doi:10.1080/10438599.2019.1610547.
Mason, G., and K. Wagner. 2005. "Restructuring of Automotive Supply-Chains: The Role of Workforce Skills in Germany and Britain." *International Journal of Automotive Technology and Management* 5 (4): 387–410. doi:10.1504/IJATM.2005.008582.
McKinsey Global Institute. 2012. *Manufacturing the Future: The Next Era of Global Growth and Innovation*. McKinsey Global Institute.
Metcalfe, S. 2005. "Systems Failure and the Case for Innovation Policy." In *Innovation Policy in a Knowledge-Based Economy: Theory and Practice*, edited by P. Llerna and M. Matt, 47–74. Berlin: Springer.
Metcalfe, S. 2007. "Innovation Systems, Innovation Policy and Restless Capitalism." In *Perspectives on Innovation*, edited by F. Malerba and S. Brusoni, 441–54. Cambridge: Cambridge University Press.
Miörner, J., and M. Trippl. 2017. "Paving the Way for New Regional Industrial Paths: Actors and Modes of Change in Scania's Games Industry." *European Planning Studies* 25 (3): 481–497.
MIT Open Learning. 2020. *The Workforce Education Project*. Cambridge, MA: MIT Open Learning.
NAESM. 2017. *Building America's Skilled Technical Workforce*. Washington, DC: The National Academies Press.
Nelson, R. 1992. "National Innovation Systems: A Retrospective on a Study." *Industrial and Corporate Change* 1 (2): 347–374. doi:10.1093/icc/1.2.347.
Nelson, R., and N. Rosenberg. 1993. "'Technical Innovation and National Systems." In *National Systems of Innovation: A Comparative Study*, edited by R. Nelson, 3–21. Oxford: Oxford University Press.
OECD. 2005. *Oslo Manuel: Guidelines for Collecting and Interpreting Innovation Data*. Paris: OECD.
OECD. 2015a. *OECD Innovation Strategy 2015: An Agenda for Policy Action*. Paris: Organisation for Economic Co-operation and Development.
OECD. 2017. *Getting Skills Right: United Kingdom*. Paris: Organisation for Economic Co-operation and Development.
Ostrom, E. 1990. *Governing the Commons*. Cambridge: Cambridge University Press.
Perkins, J. 2019. *Engineering Skills for the Future: The 2013 Perkins Review Revisited*. London: Royal Academy of Engineering.
Pfeiffer, S. 2015. *Effects of Industry 4.0 on Vocational Education and Training*. Vienna: Institute of Technology Assessment.
Porto Gómez, I., J.M. Zabala-Iturriagagoitia, and U. Aguirre Larrakoetxea. 2018. "Old Wine in New Bottles: The Neglected Role of Vocational Training Centres in Innovation." *Vocations & Learning* 11 (2): 205–221. doi:10.1007/s12186-017-9187-6.
Prais, S. 1995. *Productivity, Education and Training: An International Perspective*. Cambridge: Cambridge University Press.
Robinson, D., and G. Dominguez-Reig. 2020. *An International Comparison of Technical Education Funding Systems: What Can England Learn from Successful Countries?*. London: Education Policy Institute.
Rosenberg, N. 1976. *Perspectives on Technology*. Cambridge: Cambridge University Press.
Rosenberg, N. 1982. *Inside the Black Box: Technology and Economics*. Cambridge: Cambridge University Press.
Rupietta, C., and U. Backes-Gellner. 2019. "How Firms' Participation in Apprenticeship Training Fosters Knowledge Diffusion and Innovation." *Journal of Business Economics* 89 (5): 569–597. doi:10.1007/s11573-018-0924-6.

Ryan, P., H. Gospel, and P. Lewis. 2006. "'Educational and Contractual Attributes of the Apprenticeship Programmes of Large Employers in Britain." *Journal of Vocational Education & Training* 58 (3): 359–383. doi:10.1080/13636820600955807.

Ryan, P., H. Gospel, and P. Lewis. 2007. "Large Employers and Apprenticeship Training in the UK." *British Journal of Industrial Relations* 45 (1): 127–153. doi:10.1111/j.1467-8543.2007.00605.x.

Sainsbury, D. 2018. *Post-18 Education & Funding Review: Response by Lord Sainsbury of Turville to the Call for Evidence*. London: Gatsby Foundation.

Sainsbury, D. 2020. "Toward a Dynamic Capability Theory of Economic Growth." *Industrial and Corporate Change* 29 (4): 1047–1065. doi:10.1093/icc/dtz054.

Smith, K. 2000. "Innovation as a Systemic Phenomenon: Rethinking the Role of Policy." *Enterprise and Innovation Management Studies* 1 (1): 73–102. doi:10.1080/146324400363536.

Smith, K. 2005. "Measuring Innovation." In *The Oxford Handbook of Innovation*, edited by J. Fagerberg, D. Mowrey and R. Nelson, 148–77. Oxford: Oxford University Press.

Smith, K. 2010. "Globalisation and Innovation Systems: Policy Issues." In *Innovation Policy: Theory and Practice. An International Handbook*, edited by R. Smits, S. Kuhlman, and P. Shapira. London: Edward Elgar.

Sotarauta, M., and R. Pulkkinen. 2011. "Institutional Entrepreneurship for Knowledge Regions: In Search of a Fresh Set of Questions for Regional Innovation Studies." *Environment & Planning C, Government & Policy* 29 (1): 96–112. doi:10.1068/c1066r.

SPR 2020. *State of California Employment Training Panel Program Assessment*. Available online at: https://spra.com/wp-content/uploads/2022/09/SPR_ETP_ProgramAssessment-March2020.pdf. Accessed 17th March 2023.

Steedman, H. 2010. *The State of Apprenticeship in 2010*. London: LSE Centre for Economic Performance.

Stevens, M. 1999. "Human Capital Theory and UK Vocational Training policy'." *Oxford Review of Economic Policy* 15 (1): 16–32. doi:10.1093/oxrep/15.1.16.

Tether, B., A. Mina, D. Consoli, and D. Gagliardi. 2005. *A Literature Review on Skills and Innovation. How Does Successful Innovation Impact on the Demand for Skills and How Do Skills Drive Innovation?*. Manchester: ESRC Centre for Research on Innovation and Competition.

Toner, P. 2011. *Workforce Skills and Innovation: An Overview of Major Themes in the Literature*. Paris: OECD.

Toner, P., and R. Dalitz. 2012. "Vocational Education and Training: The *Terra Incognita* of Innovation Policy." *Prometheus* 30 (4): 411–426. doi:10.1080/08109028.2012.746412.

Toner, P., and R. Woolley. 2016. "Perspectives and Debates on Vocational Education and Training, Skills and the Prospects for Innovation." *Revista Española de Sociologia* 25: 319–342.

UKCES. 2015. *Growth Through People: Evidence and Analysis*. Wath-upon-Dearne: UKCES.

Vona, F., and D. Consoli. 2014. "Innovation and Skill Dynamics: A Life-Cycle Approach." *Industrial and Corporate Change* 24 (6): 1393–1415. doi:10.1093/icc/dtu028.

Vorley, T., and J. Nelles. 2019. *From Silos to Systems: Insights and Implications for Productivity Policy*. PIN – 12. Evidence Review. Sheffield: Productivity Insights Network.

Wolf, A. 2015. *Heading for the Precipice: Can Further and Higher Education Funding Policies Be Sustained?*. London: The Policy Institute at King's College London.

Wolter, S. C., and P. Ryan. 2011. "Apprenticeship." In Handbook of the Economics of Education, *Volume 3*, edited by R. Hanushek, S. Machin, and L. Wossmann, 521–76. Amsterdam: Elsevier.

Zahra, S., and G. George. 2002. "Absorptive Capacity: A Review, Reconceptualization, and Extension." *Academy of Management Review* 27 (2): 185–203. doi:10.2307/4134351.