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The fourth industrial revolution: the implications of technological disruption for Australian VET

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RESEARCH REPORT

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About the research

The Fourth Industrial Revolution: the implications of technological disruption for Australian VET

Pi-Shen Seet, Edith Cowan University; Janice Jones, John Spoehr and Ann-Louise Hordacre, Flinders University

Much discussion has occurred about the impact that technological disruption will have on the Australian workforce. A recent paper by the National Centre for Vocational Education Research (NCVER), *Skilling for tomorrow* (Payton 2017), examines the various ways by which the growth in technological advance is reshaping the labour market, workforce and jobs. Despite uncertainty about the scale and nature of the effect, there is a growing consensus that Australia's tertiary education system needs to change to meet the requirements of a future labour force focused on innovation and creativity. This research examines the relationship between emerging — or disruptive — technologies and the skills required, with a focus on the anticipated necessary skills from the perspective of both the innovators (technology producers) and industry (technology users). In this research the term 'disruptive technologies' refers to large-scale technology/market changes occurring through technological advances such as automation, advanced robotics and virtualisation.

The research finds that disruptive technologies are influencing the demand for both technical and soft skills in many occupations, with some skills in decline and others in higher demand. The impacts of disruptive technologies on firms are likely to differ according to firm size, stage of development, and their capability and capacity to innovate. The effects will also differ depending on the purpose for which the disruptive technologies have been introduced.

Key messages

- The demand for digital skills is expected to rise. Larger firms use in-house training to help fill gaps, including those identified in vocational education and training (VET) courses. Smaller firms, however, tend to hire workers with the required skill set, demonstrating the importance of the VET and higher education sectors in adequately skilling workers for digital disruption.
- Specialist technology-related skills are, unsurprisingly, important to disruptive technologies. However, generic non-technical skills, such as teamwork, problem-solving, continuous learning and creativity are also integral to the uptake and implementation of disruptive technologies in the workplace.
- Firms in this study view university graduates with technology-related skills, particularly higher-level technological skills, as more valuable than employees with VET qualifications. This probably reflects the sectors in which the firms are concentrated.
- Several barriers prevent the VET sector from better developing the skills required for emerging, disruptive technologies. These impediments include:

- the lack of strong integration between the VET and higher education sectors. Stronger integration would assist in the development of both the theoretical knowledge and skills (technical and soft) that workers need
- resourcing constraints and frequent restructuring in the VET sector, hampering the sectors ability to plan and execute the changes required to prepare itself and students for disruptive technologies
- the limitations of training packages, impeding the flexibility of training to respond to rapidly changing disruptive technologies.

The Industry 4.0 Industry Reference Committee (IRC), recently announced, will help to ensure that vocational education provides students with the future-focused skills they will need as a consequence of increased automation and digitalisation in the workplace, demonstrating that some steps are already being made to address some of the issues highlighted in this research.

Dr Mette Creaser
Interim Managing Director, NCVER

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The disruptive impacts of technology are amplified by their interaction with each other and will affect demand for specific skills and capabilities.

Project overview and objective

Technological innovation is seen as an engine for sustainable economic development and a driver of productivity growth. It is also widely accepted that the disruptive impacts of technology are amplified by their interaction with each other in the so-called 'Fourth Industrial Revolution' (Industry 4.0 or i4.0). Collectively, this has important implications for employment and training, particularly the demand for specific skills and capabilities. The extent to which advanced technologies and business-model innovation are more disruptive than the changes that have taken place during previous periods of technological and economic change is a subject of considerable debate. At the centre of this are widely divergent views about the potential impact of automation and artificial intelligence on occupational and skills demand.

The focus of this report is to provide insights into the potential implications for vocational education and training (VET) of the 'disruptive technologies' associated with Industry 4.0 from the perspective of industry (technology users) and innovators (technology producers). Here, the term 'disruptive technologies' refers to large-scale technology/market changes as a consequence of technological advances such as automation, advanced robotics and virtualisation.

Scope and method

The research project was qualitative in nature and involved:

- a literature review that explored the existing research on disruptive technology and its impact on jobs, work and skills
- semi-structured interviews with selected firms in advanced manufacturing and information technology (IT), which are the industrial sectors we have identified as likely to be significantly affected by disruptive technologies. Interviews were also held with technology providers and key VET sector stakeholders involved in training and policy development to prepare future workers for these industries
- two case studies that illustrate vocational education and training in disruptive technologies associated with Industry 4.0:
  - REDARC: an enterprise undergoing Industry 4.0 transformation, which specialises in the research, design, development and manufacture of electronic products, particularly for automotive applications. It has a dedicated focus on building awareness among training providers of the potential for Industry 4.0 technologies
  - Swinburne University's Advanced Manufacturing and Design Centre or Factory of the Future Testlab: an overview of an Industry 4.0 apprenticeship.

Project findings

We explored four research objectives, with the findings for each summarised below:

Research objective 1: The relationship between disruptive technologies and demand for skills

Disruptive technologies are influencing the demand for skills and capabilities in many occupations, with a decline in demand in some skills linked to routine tasks, and a growth in demand for knowledge and skills linked to the development of the digital economy. The research found that the adoption of disruptive technologies has changed the nature of some existing jobs and in doing so has expanded the range of tasks, such as problem-solving and collaboration, creating the need for additional skills and knowledge.

The Industry 4.0 agenda sees an accelerating digitalisation and the consequent demand for digital knowledge, skills and capabilities. While some skills, and the education and training that sustains them, will be rendered obsolete, the demand for digital skills and capabilities is expected to rise sharply, requiring education and training providers to adjust program offerings to meet this demand. This, however, may be limited by the content of training packages.

While larger firms implement in-house training to help fill gaps, including those that exist in VET courses, smaller firms tend to hire workers with the required skill set.

Research objective 2: Specialist skills versus generic skills for disruptive technologies

Specialist technology-related skills are important to disruptive technologies, especially in information technology and advanced manufacturing firms, which seek employees from a range of engineering (for example, design, electronics and electrical, mechatronics, mechanical and chemical) and computer science/software development disciplines.

Firms in the study viewed university graduates with technology-related skills, particularly higher-level technological skills, as more valuable than employees with VET qualifications. This probably reflected the engineering and computer science sectors in which the selected firms were concentrated.

Employers emphasised the importance of generic non-technical skills and competencies, reflected in employees whose skills and knowledge went beyond utilising technology per se, to include teamworking, creativity and problem-solving to explore and deploy technologies effectively in workplaces.

Research objective 3: Technology innovators' and the employers' perspectives on skills acquisition and development for disruptive technologies

There appears to be consensus among technology innovators and employers on the need to enhance skill development for disruptive technology, with skill needs varying according to the nature of the technology. However, when considering specific technologies, there is substantial uncertainty about the skills needed and how the training should be delivered.

Sometimes the drive to train for the use of disruptive technology does not come from industry or the VET sector, but from the students themselves. For example, drone technology (which is now more accessible due to lower costs) has become quite ubiquitous among hobbyists, resulting in its adoption in a VET sector course.

Research objective 4: Barriers to VET students' and graduates' skill acquisition and their ongoing skill development in the context of disruptive technologies

While there was consensus amongst employers on the importance of science, technology, engineering and mathematics (STEM) skills development, employers believe that, in general, employees lack the necessary STEM skills. This then adversely impacts on their ability to develop the required technical skills and complete their training, including their ability to successfully complete apprenticeships.

In the VET sector, reduced resourcing, organisational changes and policy uncertainty, combined with the limitations of training packages, resulted in many VET trainers perceiving that they lacked capacity in terms of preparing themselves and their students for disruptive technologies. VET sector staff engaged in program development and teaching also pointed to training packages as a significant barrier to enabling them to train and prepare students for disruptive technologies. Interviewees described how the prescriptive nature of training packages limits their ability to introduce new elements into their training.

This finding is also reflected in the fact that some employers reported difficulties in finding public and/or private providers with the capacity to provide education and training in specific disruptive technologies.

Summary and ways forward

The implementation of disruptive technologies such as automation, advanced robotics and simulation/virtualisation at the firm level is impacting on the demand for skills and capabilities, particularly those that enable digitalisation, while reducing or eliminating tasks that might be displaced by technologies. While the scale of the job losses caused by disruptive technologies has been greatly debated, it is widely accepted that these technologies will have significant impacts on the demand for particular skills and capabilities and, consequently, on the VET sector.

Based on these findings, the following suggestions are made to assist the VET sector to better prepare its educators, students and graduates for the impact of disruptive technologies in the future workplace:

- Given that emerging disruptive technologies will change the nature of existing jobs, training solutions should be developed that allow for the expanded scope of tasks in existing jobs/roles/positions, with an increase in the range of knowledge and skills with which job holders need to be equipped in order to utilise these technologies.
- Besides developing technical skills and knowledge relevant to disruptive technologies, it is equally important to enhance the development of 'generic' or soft skills, as these are essential for preparing workers to be flexible and to cope with the rapid changes in the future workplace as a result of disruptive technologies.

- The disruptive nature of some advanced technologies has implications for the demand for skills, course content, and the knowledge and skills of the VET workforce, all of which have implications for VET planning, offerings and delivery.
- To better manage the ongoing changes introduced by disruptive technologies, the VET sector and employers need to work together to support the updating and upgrading of the lifelong learning skills of VET graduates.
- Disruptive technology, particularly pervasive digitalisation, is eroding the traditional boundaries between jobs. Recent moves towards developing cross-industry units, skill sets and qualifications, and their adoption across multiple industries, will help to address this. This approach needs to be accelerated.

Background

Defining disruptive technology

It is not clear whether the impact of disruptive technologies on employment opportunities and skills will be positive.

Technological innovation is seen as an engine for sustainable economic development and a driver of productivity growth. In the past, technological innovation has been linked to changes in work and employment. However, a range of disruptive technologies — an all-encompassing term for the large-scale change that arises from the specific technologies of robotics and automation (Hynes, Elwell & Zolkiewski 2016) — are expected to cause rapid and major disruptions to the demand for occupations and skills. This is a consequence of the amplification or multiplier effect of such technologies, interacting with each other as part of the so-called Fourth Industrial Revolution (World Economic Forum 2016).

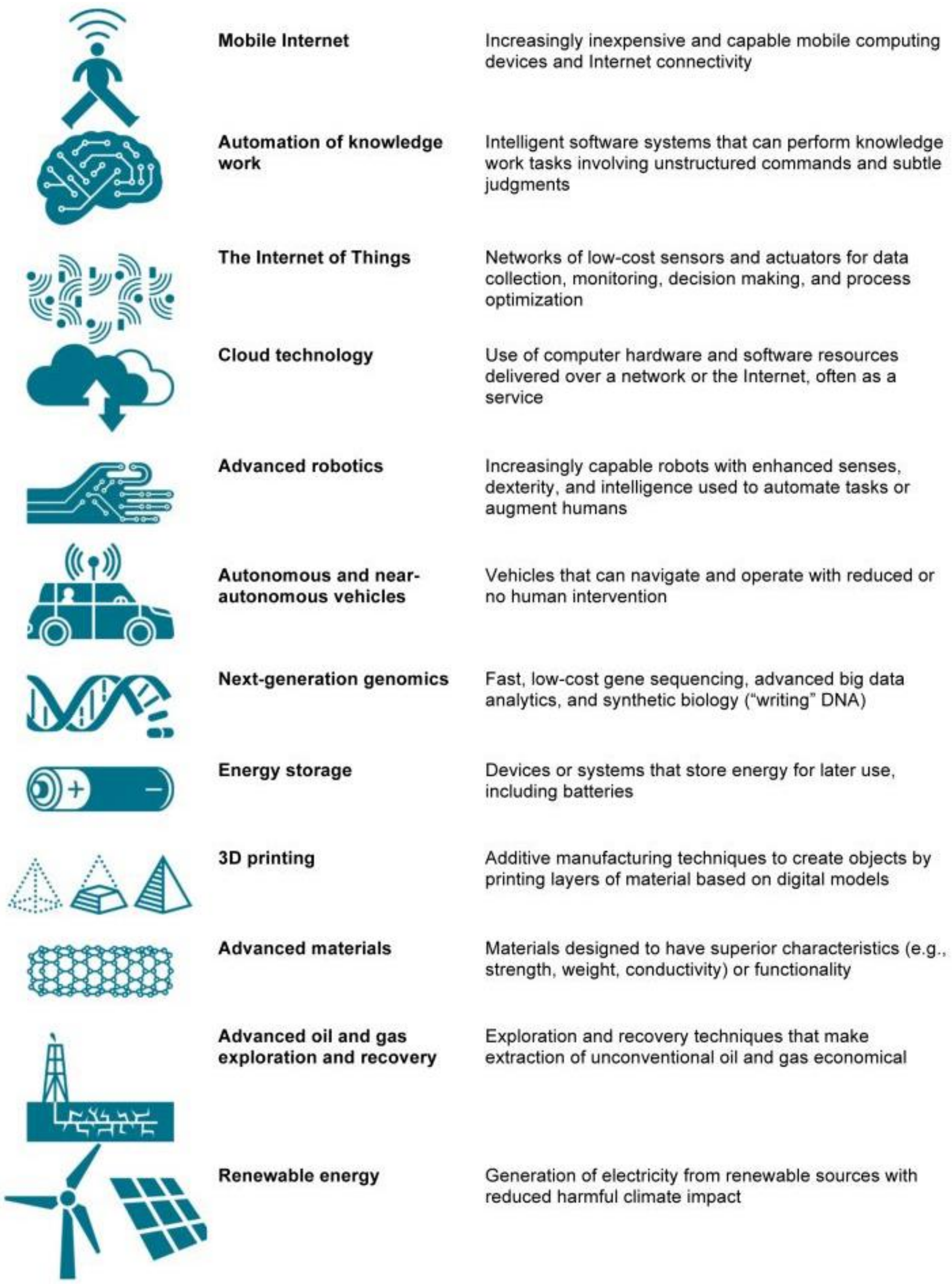
In 1978, Abernathy and Utterback (1978) described disruptive technologies as those that create entirely new technology or market paradigms, but the term was not widely used until almost 20 years later. Although they were not the first to recognise that new innovations could result in significant disruption, in a 1995 article titled 'Disruptive technologies: catching the wave', Joseph Bower and Clayton Christensen popularised the idea that certain new technologies can disrupt or radically change the established order in existing markets or even create new markets (Bower & Christensen 1995). In 1997, Clayton Christensen published his bestselling book, *The innovator's dilemma*, which elaborated on the concept of disruptive technologies proposed in his earlier paper (Bower & Christensen 1995). According to Christensen, disruptive technologies are those that are initially inferior to existing mainstream technologies. However, due to the rapid improvement or over-performance of these technologies in important attributes valued by existing customers, combined with a lack of incentives among existing healthy firms to change and innovate, the products based on the new technologies displace the existing mainstream products, thereby resulting in a market disruption. By the early 2000s, disruptive technologies were attracting a great deal of attention, with claims that they constituted a new industrial revolution (Berman 2012; The Economist 2012). For others, the changes taking place are more evolutionary than revolutionary. Nonetheless, technology forecasters have identified groups of disruptive technologies (for example, artificial intelligence, 3D printing, advanced materials, and nanotechnology) that build on and amplify each other, as well as interact with the wider socioeconomic, geopolitical and demographic factors underlying the transformation of industries (Manyika et al. 2013; World Economic Forum 2016). Table 1 and Figure 1 define and illustrate common disruptive technologies.

Table 1 Nine disruptive technology categories identified by the World Economic Forum

Driver of change	Rated as top trend	Expected timeframe	Definition
Mobile internet and cloud technology	34%	2015–17	The mobile internet has applications across business and the public sector, enabling more efficient delivery of services and opportunities to increase workforce productivity. With cloud technology, applications can be delivered with minimal or no local software or processing power, enabling the rapid spread of internet-based service models.
Advances in computing power and 'big data'	26%	2015–17	Realising the full potential of technological advances will require having in place the systems and capabilities to make sense of the unprecedented flood of data these innovations will generate.
New energy supplies and technologies	22%	2015–17	New energy supplies and technologies, such as renewables and hydraulic fracturing (fracking), are shaking up the global energy landscape and disrupting powerful players at least as much as yesterday's oil price crises did, with profound and complicated geopolitical and environmental repercussions.
The Internet of Things	14%	2015–17	The use of remote sensors, communications, and processing power in industrial equipment and everyday objects will unleash an enormous amount of data and the opportunity to see patterns and design systems on a scale never before possible.
Crowdsourcing, the sharing economy and peer-to-peer platforms	12%	Impact felt already	With peer-to-peer platforms, companies and individuals can realise achievements that previously required large-scale organisations. In some cases, the talent and resources that companies can connect to, through activities such as crowdsourcing, may become more important than the in-house resources they own.
Advanced robotics and autonomous transport	9%	2018–20	Advanced robots with enhanced senses, dexterity, and intelligence can be more practical than human labour in manufacturing, as well as in a growing number of service jobs, such as cleaning and maintenance. Moreover, it is now possible to create cars, trucks, aircraft, and boats that are completely or partly autonomous, which could revolutionise transportation, if regulations allow, as early as 2020.
Artificial intelligence and machine learning	7%	2018–20	Advances in artificial intelligence, machine learning, and natural user interfaces (for example, voice recognition) are making it possible to automate knowledge-worker tasks that have long been regarded as impossible or impractical for machines to perform.
Advanced manufacturing and 3D printing	6%	2015–17	A range of technological advances in manufacturing technology promises a new wave of productivity. For example, 3D printing (building objects layer by layer from a digital master design file) allows on-demand production, which has far-ranging implications for global supply chains and production networks.
Advanced materials, biotechnology and genomics	6%	2018–20	Technological advances in the material and life sciences have many innovative industry applications. Recent breakthroughs in genetics could have profound impacts on medicine and agriculture. Similarly, the manufacture of synthetic molecules via bio-process engineering will be critical to pharmaceuticals, plastics and polymers, biofuels, and other new materials and industrial processes.

Source: World Economic Forum (2016).

Figure 1 Twelve disruptive technology categories identified by the McKinsey Global Institute



Mobile Internet	Increasingly inexpensive and capable mobile computing devices and Internet connectivity
Automation of knowledge work	Intelligent software systems that can perform knowledge work tasks involving unstructured commands and subtle judgments
The Internet of Things	Networks of low-cost sensors and actuators for data collection, monitoring, decision making, and process optimization
Cloud technology	Use of computer hardware and software resources delivered over a network or the Internet, often as a service
Advanced robotics	Increasingly capable robots with enhanced senses, dexterity, and intelligence used to automate tasks or augment humans
Autonomous and near-autonomous vehicles	Vehicles that can navigate and operate with reduced or no human intervention
Next-generation genomics	Fast, low-cost gene sequencing, advanced big data analytics, and synthetic biology ("writing" DNA)
Energy storage	Devices or systems that store energy for later use, including batteries
3D printing	Additive manufacturing techniques to create objects by printing layers of material based on digital models
Advanced materials	Materials designed to have superior characteristics (e.g., strength, weight, conductivity) or functionality
Advanced oil and gas exploration and recovery	Exploration and recovery techniques that make extraction of unconventional oil and gas economical
Renewable energy	Generation of electricity from renewable sources with reduced harmful climate impact

Source: Manyika et al. (2013).

In spite of the continuing influence of Christensen's work and those of his collaborators and supporters (or as a result of this), the definition, characteristics, drivers and outcomes of 'disruptive technologies' have been hotly debated and contested (Nagy, Schuessler & Dubinsky 2016).

As Möslein and Neyer (2015) note, the term 'disruptive technology' has moved away from:

> its original focus on technological innovations and has been widely used to describe almost every type of innovation, from radically new products, processes and services to discontinuous business models, change process, and value propositions. This broad use of the term undermines the usefulness of a powerful concept of disruptive technologies and their strategic impact on organizations and markets. (p.1)

While we acknowledge that disruptive innovations may include broader aspects of disruption, such as business-model innovation (Christensen, Bartman & Van Bever 2016), and disruptive service and product innovations (Christensen & Raynor 2003), we follow Markides (2006) in treating disruptive technology as distinct from other disruptive phenomena. As such, our research focuses on the impact of disruptive technologies as a subset of disruptive innovations.

We also follow Hynes, Elwell and Zolkoiewski (2016) in using the term 'disruptive technology' as an all-encompassing term for large-scale technology/market changes. To this end, we adopt the definition of 'disruptive technology' based on Nagy, Schuessler and Dubinsky's (2016) modification of earlier work (Danneels 2004; Markides 2006; Tellis 2006) as:

> technology that changes the performance metrics or consumer expectations of a market by providing radically new functionality, discontinuous technical standards, or new forms of ownership which may have relatively different disruption effects on existing market players. (p.121)

Research objectives

This study explores industry perspectives on the skills needed to support the uptake and diffusion of the disruptive technologies associated with the Fourth Industrial Revolution, and, in particular, the skills required from VET graduates in Australia over the next five to 10 years. It explores the link between innovations and more fine-grained occupational characteristics (Vona & Consoli 2015). It also addresses a previously identified gap in Australian VET research, in that much of VET research has focused on the supply side of the training market, while the demand side (industry/enterprise) remains relatively under-researched (Smith & Hayton 1999; Tomlinson 2017). Research has been driven by the perceived need to reform the public provision of training to create a more highly skilled national workforce, one on which enterprises can draw to improve their competitiveness. However, relatively less is known about the demand side. In particular, the processes of training within the enterprise, while often maligned publicly as being low in quantity and quality, have remained relatively unexplored. Thus, the main research questions and objectives are:

To examine the relationship between *disruptive technologies and skill development needs in the VET sector from the perspective of industry (technology users) and innovators (technology producers)*

1. What is the nature of the relationship between disruptive technologies and demand for skills?
2. To what extent are specialist skills versus generic skills relevant to the implementation of disruptive technologies?
3. To what extent is there consensus between the technology innovators and end-use employers when it comes to skills acquisition/development for disruptive technologies?
4. What are the barriers to VET students' and graduates' skill acquisition and development in the next five to 10 years in the context of disruptive technologies?

In the next section, we review the literature on disruptive technologies and skills. The third section describes the qualitative methods used to conduct the research, followed by the key findings. Two illustrative case studies are also presented in this section. The report concludes with a discussion of the results, identifying key policy implications.

Will disruptive technologies lead to job losses? The oft-cited high proportion of jobs at risk from automation has been challenged by some researchers.

Literature review

This literature review explores existing research on disruptive technology and its impact on jobs, work and skills.

Characteristics of disruptive technology

The three generally recognised characteristics of 'disruptive technology' or 'technological disruption' can be summarised as follows:

- Unlike 'sustaining technologies', which tend to have a constant or incremental rate of improvement to existing customers, 'disruptive technologies' produce a radically different set of values, thereby disrupting the status quo. Their value may be due to much lower costs of production as a result of innovation (Bower & Christensen 1995); or it may be due to innovations changing the performance of the existing products and consumer expectations (Danneels 2004; Tellis 2006).
- In having the potential to change the market, disruptive technologies in themselves normally display significant innovative characteristics through radical changes in functionality and/or discontinuous change in technical standards and/or new forms of ownership (Nagy, Schuessler & Dubinsky 2016; Thomond & Lettice 2002).
- Disruptive technology effects are relative and do not affect all players in the market equally: they may be 'disruptive to some but sustaining to others' (AlphaBeta 2017; Bower & Christensen 1995). This means that technological disruption is sensitive to existing organisational contexts and strategies and current technologies and practices (Nagy, Schuessler & Dubinsky 2016). To that end, depending on how ready an organisation is for the disruption, or where they are in the value chain and market, the disruptive technology can result in quite different outcomes.

It is the third characteristic that we will address in more detail later in this report, as it allows for market players and stakeholders to prepare for and 'manage' disruption (Gans 2016). This is in contrast to the original conceptualisation of disruptive technology, whereby incumbents were faced with an apparently insolvable 'innovator's dilemma', one in which they were unable to continue to improve or deploy their existing technology and were at the mercy of the new disruptive technology being introduced by more nimble disrupters (Christensen, 1997).

Impact of disruptive technology

There is a lack of agreement about the exact nature of the impacts of disruptive technologies. While some see the full range of existing disruptive technologies offering limitless new opportunities, others argue they will lead to significant job losses and tasks within jobs (Frey & Osborne 2013; Dolphin 2015; AlphaBeta 2017; Chartered Accountants Australia and New Zealand & Deloitte Access Economics 2016; Department of Industry, Innovation and Science 2017). Even after using a new research and planning methodology such as Strategic Foresights, the CSIRO, working with the Boston Consulting Group (BCG), developed several different scenarios of how disruptive technologies and other 'megatrends' would impact on future jobs and employment (Hajkowicz et al. 2016).

This uncertainty and lack of agreement on the impact of disruptive technologies has slowed adoptions among corporations, governments and communities.

It has been claimed that these technologies can lead to large changes in employment (Manyika et al. 2013; Petrick & Simpson 2013). In Australia, for example, Durrant-Whyte (2015) estimates that 40% of employment has a high risk of being automated over the next 10 to 15 years, given existing technologies. Similarly, in the United States, it is estimated that 47% of jobs are at risk of automation over the next decade or two (Frey & Osborne 2013), while globally, by 2025, up to 140 million knowledge workers are estimated to be vulnerable to job loss as a consequence of artificial intelligence (Manyika et al. 2013).

However, there has been a lack of consensus on the potential volume of job losses from disruptive technology, largely due to researchers using different methodologies and focusing on different processes to explain how technological disruption leads to changes in jobs. For example, this could be the result of substitution effects (Hirsch-Kreinsen 2016) and whether technological disruption affects change at the occupation level (Frey & Osborne 2013), task level (Arntz, Gregory & Zierahn 2016) or skill level (Pfeiffer & Suphan 2011). The high proportion of jobs at risk from automation has been challenged by a growing body of research focusing on the relative vulnerability of tasks and, by extension, occupations. This research indicates that between eight to 30% of occupations have high levels of vulnerability (Arntz, Gregory & Zierahn 2016; Berriman & Hawksworth 2017).

While there has been an ongoing debate on whether broader socioeconomic, geopolitical and demographic developments or social or technological factors have been changing and will change the nature of work, all have been found to contribute in similar orders of magnitude (World Economic Forum 2016). Because the original definition and focus of disruptive technology was on market disruption, most of the outcomes in terms of research, as highlighted above, emphasise the market side. However, given that organisations are disrupted in different ways, depending on how prepared they are or their position in the value chain, research has increasingly begun to investigate the wider impacts of technological disruption.

Disruptive technology and work

As noted in the previous section, disruptive technology does not impact on the workforce equally and this was identified by early Australian researchers in the field:

> the challenges faced by the workforce in responding to the changing demands in the workplace are not homogenous. Some parts of the workforce may already be experienced in handling the introduction of disruptive technologies, while others may have been employed in an industry using relatively long-term stable production technology and processes, and having little or no experience in coping with disruptive change. The latter group can be expected to face more significant challenges in dealing with these changes, and will, in all probability, need greater support and understanding from the VET sector and employers.
>
> (Bennett, Brunker & Hodges 2004, p. 75)

While earlier studies attempt to identify the types of industries and jobs susceptible to disruptive technologies, automation in particular (Durrant-Whyte 2015; Frey & Osborne 2013; Manyika et al. 2013), less research has focused on the potential structural consequences for job activities and changes in skill needs at the firm level (Hirsch-Kreinsen 2016; Leipziger & Dodev 2016).

The research that does exist is largely based on studies in Europe and is directed at the social and macro-structural consequences of digitisation for industrial work, or the so-called Industry 4.0 in Germany (Hirsch-Kreinsen 2016; Leipziger & Dodev 2016). For example, Hirsch-Kreinsen (2016) argues that the implications of the digitisation of work for employee skills or qualifications are quite divergent. On the one hand, the required worker qualifications have been 'upgraded', although the extent to which an increase in qualifications affects different employee groups is less clear cut. On the other hand, a 'polarisation' of qualifications has become evident. There is an increased demand for high-qualification job activities (for example, managerial, technical and professional) or creative, innovative communicative activities (e.g. the ability to communicate complex problems among heterogeneous interdisciplinary and interorganisational teams using different technical communication and cooperation systems in different languages) (Erol et al. 2016), and maintenance roles. In the service and industrial sectors, the expansion of less demanding, but non-routine, activities (not amenable to automation) is possible. Jobs requiring intermediate skill levels are increasingly automated, as are routine activities such as monitoring tasks (Erol et al. 2016). The result is a differentiated job-activities structure, characterised by sophisticated high-skill job activities on the one hand, and some specialist but devalued tasks and non-automated simple activities on the other (Buhr 2015; Windelband 2011).

Recent research in the United States found that automation will eliminate very few occupations entirely in the next decade, but it will affect portions of almost all jobs to some extent, depending on the type of work (Chui, Manyika & Miremadi 2016; Manyika et al. 2013). Similarly, in a study on automation of jobs for 21 Organisation for Co-operation and Development (OECD) countries based on a task-based approach, Arntz, Gregory and Zierahn (2016) found that, on average, only 9% of jobs are automatable and the threat from technological advances seems much less pronounced compared with the occupation-based approach. In addition, they found differences across OECD countries (for example, the share of automatable jobs is 6% in Korea, the corresponding share is 12% in Austria) and argue that differences between countries may be the result of variances in workplace organisation, previous investments into automation technologies, and education of workers across countries.

Disruptive technology, (new) knowledge, skills and attributes

What determines the actual development path — upgrading versus polarisation (Hirsch-Kreinsen 2016), or the extent of polarisation (Buhr 2015), or the structure of work organisation — in practice likely depends on the automation design concept and its implementation (Hirsch-Kreinsen 2016). The research identifies three alternative concepts or scenarios of automation:

- ***Technology-centred automation concept*:** here systems direct people and automation replaces less skilled workers. Research suggests that monitoring and control tasks are taken over by technology, which prepares and distributes information in real time (Buhr 2015). Employees respond to the needs of cyber-physical systems (CPS) and are primarily responsible for executive tasks. Cyber-physical systems 'are the enabling technologies bringing the virtual and physical dimensions together in manufacturing to create a truly networked domain in which intelligent objects communicate and interact with each other'(p.10) (Subic & Gallagher 2017). According to Buhr (2015), however, far-reaching replacements of work functions by automation occurs, with tasks for workers limited to those that cannot be automated, or can only be automated with significant difficulty.

- ***Hybrid scenario***: here monitoring and control tasks are performed via cooperative and interactive technologies, networked objects and people (Buhr 2015). Under this scenario, the distribution of tasks between employees and machines is based on the relative strengths and weaknesses of workers vis-à-vis machines (Hirsch-Kreinsen 2016). However, employees will face increased demand to be highly flexible.
- ***Specialisation scenario*****:** here people use systems, and cyber-physical systems are used as a tool to aid decision-making. Thus, the dominant role of qualified workers remains.

Buhr (2015) suggests that there will be an amalgamation of traditional production line and knowledge workers' tasks, leading to more efficient and effective processes. In addition, a variety of new assistance systems will be developed, while administrative and production processes are increasingly automated. This has implications for the distribution of tasks between information technology and production technology workers, with IT competencies expected to increase in importance and merge with production—technical competencies (Hirsch-Kreinsen 2016). This may also be a barrier to the implementation of the new smart production system, in those instances where technical experts use their position to slow down or block it, fearing loss of competence/autonomy or the surveillance potential of the new digital system (Hirsch-Kreinsen 2016).

New opportunities will however open up, particularly for highly qualified workers involved in design, problem-solving and team building. These trends are consistent with the polarisation of employment or work, whereby certain jobs with mid-level skill requirements will be substituted by automation, while vocations at the lower and upper ends of the qualification spectrum, which are less automatable and based more on experience and interaction, will increase in importance.

Impact of disruptive technology in the Australian context

While there has been some research in the Australian context that was conducted more than a decade ago on the impending impact of disruptive technology on skills and training (Dawe 2004), most of the subsequent studies on the impact of technological disruption have been conducted in Europe and to a lesser extent in the United States.

Over the past few years, NCVER research has focused on the relationship between VET and innovation (Curtin, Stanwick & Beddie 2011; Stanwick 2011). However, more recent research has focused on the impact of disruptive technology in Australia (CEDA 2015; Productivity Commission 2016; Spike Innovation 2015). The Productivity Commission (2016) focused on understanding why Australian productivity (that is, multifactor productivity) has not recorded the kind of growth that would be expected from a period of change described as 'disruptive' and the role of government in the face of a potentially disruptive technological change. It argued that governments in Australia are largely reactive (as opposed to proactive) in dealing with 'digital disruption'. With regard to employment, the report acknowledged that digital disruption would have a major impact on work through automation and structural adjustment, although most of the findings related to young people with little experience and low skills, older people in industries subject to major structural change, and university graduates (for example, engineers and data analysts).

To reconcile these different perspectives, attempts are being made in Australia to identify the implications for education and training from the Industry 4.0 agenda. This is being driven by the Prime Minister's Industry 4.0 Taskforce, inspired in part by the German Government's Platform Industry 4.0 initiatives. The establishment of the taskforce has resulted in the development of test labs in Australia to illustrate the range of digital, project-coordination and soft skills that are likely to be required to support the Industry 4.0 agenda (Subic & Gallagher 2017). These are shown in table 2.

Table 2 Industry 4.0 skills

Digital skills	Project coordination skills	Soft skills
Industry 4.0 programming and software engineering	Product management	Creativity
Data science	Multi-project management	Design
Data/ big data analytics	Supply chain and support services	Innovation
Visualisation	Logistics	Leadership
Internet of Things		
IT architecture		
Security		

Source: Subic and Gallagher (2017).

Impact of disruptive technology on VET

As disruptive technology, particularly in the form of digital technology, becomes more widely deployed in workplaces, VET providers will face the challenge of understanding the implications of this change for course offerings and delivery. This is not straightforward as it requires gathering evidence at the workplace level; nonetheless, VET providers must decide which technologies to use in training.

The danger is that technology can change rapidly, sometimes within the timeframe of a student's training course, creating a risk that they may graduate with skills that are no longer relevant to employers (Reeson et al. 2016). On the other hand, care needs to be taken not to overestimate the pace of technological change, acknowledging, as we have indicated earlier, that this will vary enormously from workplace to workplace. While Moore's Law (Moore 1965) predicts that computing power will double every 18 to 24 months, the extent to which this translates into disruption is difficult to estimate. For example, there was a large rise in VET sector commencements in electronics and telecommunications trades workers between 2010 and 2013, most likely associated with the construction of the National Broadband Network, but as the relevant workforce's skills base has increased, commencements have since declined (Noonan & Pilcher 2017).

A further risk facing the VET sector arising from digital disruption is that any changes to accredited VET courses require a multi-year national consultation process, especially the current processes that create, update and endorse training packages (Torii & O'Connell 2017). The aim being to ensure that educational programs align with industry practice and needs. It has been argued for some time that too much bureaucratic red tape and unnecessary detail mean that the existing VET system is sluggish in responding to emerging needs in a timely fashion (Misko 2010). Thus providers of accredited training have very little freedom to respond rapidly to changes in technology and their skill requirements, putting them at a competitive disadvantage to providers of training who are not nationally accredited but who have greater flexibility to change the content of training (Reeson et al. 2016).

In addition, VET trainers need to be exposed to current and emerging technologies by undertaking training and development to enable them to be competent technology users as well as educators (Reeson et al. 2016). Disruptive technology can also impact on how and where students learn, with vocational training increasingly available online through massive open online courses (MOOCs). These courses provide learning flexibility and make skill and knowledge acquisition more accessible, convenient, engaging and potentially cheaper (Bainbridge Consulting 2015). The use of digital channels also means that educators will need a different pedagogy and skill set to complement the technology (Bainbridge Consulting 2015; Reeson et al. 2016).

The 2016 Productivity Commission study (noted earlier) looked mainly at STEM skills and entrepreneurship education programs in the context of schools and university graduates. Lessons can be learnt by the VET sector in terms of learning that supports creative approaches and values data analysis, computing skills and lifelong learning:

> All workers need the skills to interact with digital technology, whether it is maintaining records in caring professions, taking orders in retail, or operating equipment in the processing plant (p.82).
>
> The Australian education system will need to create workers with the skills and competencies required to thrive in a continuously changing environment. The most important skill is the ability to acquire new skills — life-long learning. (p.84)

When it came to specific skill recommendations, the report focused on the changes to skill sets needed by public servants to accompany technological change.

More recently, the Australian Industry and Skills Committee (AISC) established nine cross-sector projects to reduce the levels of complexity in the VET system (AISC 2017b). In relation to disruptive technologies, the cross-sector projects will focus on emerging technologies and bring a range of industries together to determine the common skills individuals will need to transition into future jobs. As well as modernising training, this new approach recognises the importance of a flexible and adaptable workforce to business productivity and Australia’s future competitiveness. The cross-sector projects will also provide a forum for a range of industries to discuss the opportunities provided by these new technologies and the ways in which these can be translated into new competencies across the system (AISC 2017a), especially those that intersect with the strategic priorities of industry growth centres (IGCs). The expertise of these centres, along with their networks, enables unique insights into training package development and complements the expertise and knowledge of the industry reference committee (IRC) network. By way of example, the Automation Skills Cross-sector project aims to contribute to the development of training products that will support and sustain automation-enabled economic growth in Australia through the development of skilled workers (Skills Impact 2017). Among its tasks was to identify the skills shared by multiple industry sectors in relation to automation, and recommend training package developments and modifications to enable the use of training products across multiple industries, thus reducing duplication and enhancing skill transferability. This project provides early evidence that the VET sector is adopting some of the recommendations of recent research that suggest experimentation with pilots and trials to further enhance the design of the training product system (Beddie, Hargreaves & Atkinson 2017).

Even more recently, the Australian Industry and Skills Committee (2018) announced that it will establish an Industry 4.0 Industry Reference Committee, its aim being to ensure that vocational education gives students the future-focused skills they will need as workplaces are transformed by increased automation and digitalisation.

The literature review demonstrates that the ways by which individual organisations and their workforces are affected by these technological advances are likely to vary considerably. While there is little evidence of how training is adapted for disruptive technologies in practice, the review finds that a number of useful developments in Australian VET are occurring, specifically in adapting training systems to more rapidly support the adoption of new technologies in workplaces. These findings are incorporated into the design of the qualitative fieldwork, described in the next section. The fieldwork provides new evidence on how Australian firms learn about new technology to adopt and how they identify the worker types needed for operating the technology, together with their views on the desired worker skills and how they can be developed.

Research method

Introduction

The exploratory nature of the research meant that the project adopted a qualitative methodology, involving interviews with:

- firms in industries that we identified as having been or are likely to be significantly impacted by disruptive technologies (phase 1)
- key VET sector stakeholders involved in training and policy development to prepare future workers for these industries (phase 2).

Two case studies, one from industry and the second from the VET sector, were also developed to highlight a number of initiatives that could be adapted or replicated by firms and/or VET providers to facilitate skills development in disruptive technology.

These phases are described in more detail below.

Phase 1: Industry interviews

Sample

We used a purposive sampling method, with key managerial informants initially identified through industry contacts. Specifically, participants were sourced through the Innovative Manufacturing Co-operative Research Centre (IMCRC), of which Flinders University's Australian Industrial Transformation Institute (AITI) is a key participant.

There were two key criteria for inclusion in the study. First, managers were selected from firms implementing disruptive technologies (technology producers/innovators) or from industries likely to be significantly impacted by disruptive technologies (technology users/industry). Second, the selected managers had knowledge of, and some responsibility for the implementation of, disruptive technologies, as well as for skill acquisition and development in their firm. Most firms were drawn from the IT sector or were 'advanced manufacturers', which implies the implementation of a broad set of enabling disruptive technologies and practices by businesses from a wide range of industry sectors in areas such as medical technology, biopharmaceuticals, mining, agribusiness, aerospace and defence, whose aim is to produce highly specialised products and processes (Advanced Manufacturing Growth Centre 2018). With the exception of the life-science driven technologies, most of the categories identified by the World Economic Forum 2016, and the McKinsey Global Institute in Manyika et al. 2013, were represented (see table 1 and figure 1).

A total of 23 CEOs, managing directors or other members of the executive team (for example, chief technology officers) were included in the study. As noted above, we focused on senior managers since they were more likely to be involved in strategic activities and thus likely to have an accurate knowledge of disruptive technologies in the innovation context. Interviews were carried out between September 2016 and March 2017. Fourteen of these interviews were with CEOs or chief technology officers of technology start-ups or individuals who were developing small businesses using one or more disruptive technologies;

nine were CEOs or chief technology officers of larger firms that are leaders in their industries. Most of the start-ups or small businesses were in less capital-intensive sectors, such as new energy supplies, cloud technologies and mobile internet. By contrast, the larger firms tended to belong to the more capital-intensive sectors, such as advanced manufacturing and advanced materials. The key characteristics of these firms are summarised in table A1, in appendix A.

Data collection and analysis

A semi-structured face-to-face interview format was employed, ensuring that consistent topics were explored across interviewees and allowing interviewers to probe statements to clarify and explore emerging issues.

The interview protocol focused on three areas:

- background data, which related to the role and background of the executive or other manager, and the setting in which the enterprise operates
- the range of disruptive technologies utilised in the firm
- skills acquisition and development, including the range of training providers involved.

The interview questions addressed were:

- how the firm learnt about new technology
- the type of worker or technology user (specialist or generalist) required to use or operate the technology effectively
- the types of skills workers need and how they are developed.

Further details relating to the qualitative methodology are provided in appendix A.

Phase 2: VET sector interviews

Given that data on the effect of new disruptive technologies in the Australian VET sector are not readily available, a set of semi-structured interview questions was developed drawing from responses to the firm interviews in Phase 1. Most interviews related to training and skills in manufacturing, this being the industry most disrupted by new technologies. A number of interviews with VET providers engaged in emerging industries (for example, virtual reality and augmented reality), as well as more traditional services (for example, business management, hospitality), were also conducted. In total, 18 VET sector respondents were interviewed (table A2, appendix A).

The key questions addressed were:

- the aspects of the industry-identified new technologies with which VET providers were familiar
- the extent to which VET is currently training students in these technologies and the issues/challenges faced by students undertaking education and training related to disruptive technologies
- implementation issues and challenges regarding technologies identified by industry participants that VET interviewees have little past experience with, or have been unable to incorporate into VET training

- the way by which VET providers are responding to the challenges of providing specialist versus generic skills in an environment characterised by rapid change and uncertainty
- the limitations of current training packages in preparing VET students for disruptive technologies
- suggestions and ideas for addressing the issues and challenges identified by industry and VET providers and the support and resources required to overcome these challenges.

The data analysis for VET interviews followed the same method as described for Phase 1.

Case studies

Two case studies were undertaken to highlight key initiatives that could be used as exemplars and/or replicated to facilitate skills development in disruptive technology. The first case study explored an Australian firm undergoing Industry 4.0 transformation, with a focus on their skills development and training providers. The case selection was guided by the theoretical sampling process proposed by Glaser and Strauss (1967). A medium-sized advanced manufacturing enterprise (with over 150 employees) in the Adelaide area in the process of transforming to Industry 4.0 and upskilling staff through VET and other training providers was selected. This firm is involved in the research, design, development and manufacture of electronic products, in particular for automotive applications. The company specialises in energy management, charging systems, control systems and safety systems in vehicles. The second case involved Australia's first education provider to establish an Industry 4.0 apprenticeship.

Data were collected through semi-structured interviews. Desk research provided further information and comprised analyses of corporate material, newsletters, media releases and articles from newspapers and other publications.

Disruptive technologies will have significant impacts on jobs, skills and training in industry, and therefore on the VET sector.

Results and discussion

Introduction

This section provides an analysis for each of the four research objectives, beginning with the patterns which emerged from firm-level interviews, followed by the themes to emerge from the VET interviewees in relation to research objective 1. Case studies are incorporated to give examples of the role of VET in Industry 4.0 technologies.

Research objective 1: The relationship between disruptive technologies and demand for skills

The first objective of the study was to understand the nature of the relationship between disruptive technologies and the demand for skills. A clear pattern evident in the data is that disruptive technologies have disrupted skill requirements at the firm level in two ways:

- by eliminating the number of, and in some cases the need for, particular jobs
- by expanding the scope of tasks in existing jobs, with an increase in the scope of the knowledge and skills that job holders need to possess in order to utilise these technologies.

We expand these two themes below.

Pattern 1 – a reduced need for particular jobs

The application of disruptive technologies such as automation, advanced robotics and simulation/virtualisation at the firm level has meant that either a reduction in the number of required positions occurs, or the need for specific positions is eliminated. For example, industrial robotics in one firm that manufactures advanced electronics has halved the number of operators (from four to two) needed to oversee the manufacturing line, as the following quote illustrates:

> a fully automated line controlled by two operators, whereas previously, we had four operators … we still need operators obviously to make sure that the line is running correctly and do any changeovers or things like that. (Firm #2)

Similarly, a manager of a communications supplier to the defence industry describes how and why robots have replaced staff on very large military ships:

> because they've got robotics and automation in a lot of their machinery spaces to make them unoccupied … through video and remote control systems, you can operate and control systems where you would normally have people … a robotic system … will perform 24/7 and it will also do it quicker and faster and more effective[ly] … it's a novel design paradigm … the ultimate in robotics is that you're obsolete. (Firm #6)

A small solar energy firm also utilises a robotic production line to manufacture solar panels, with its owner—manager pointing to improvements in the cost base, quality and quantity of output as a consequence of the replacement of production workers with robots.

This participant noted that the types of robots they used was standard automation practice for their industry, but that the new or more novel disruptive technology was cloud computing, leading to the ability to automate administrative tasks and back office operations:

> being able to automate that part of the business, for me, has meant that we are running such a low operating expense … compared to previous experience that I've had … less than half, maybe 70, 80% less in back office admin. (Firm #1)

Another disruptive technology, simulation/virtualisation, has also had adverse implications for the number of human-resourced positions within firms. The manager of a firm that uses simulation in its engineering-design operations describes how simulation of prototypes reduces and can eliminate the need for technicians. Previously, physical prototypes required engineers and a couple of technicians for manual tasks.

However, while disruptive technologies such as automation and advanced robotics have replaced the operators responsible for many of the production tasks associated with manufacturing operations, we did not find evidence of a robot-to-robot production line, with highly skilled factory and floor staff referred to by one manager as the firm's 'most talented and smartest people' (Firm #1).

Although it was recognised that disruptive technologies could have significant impacts on jobs, there appeared to be few concerns about these technologies causing major job losses. Instead, some disruptive technologies were used to either eliminate people from risky or difficult situations, and/or to (partially) fill some of the identified workforce gaps, which is particularly the case in the armed forces and in healthcare provision. The following examples illustrate this point: the first is a defence-based organisation which employs drones in situations where crewed flight is considered too risky or difficult, and the second is a firm that uses relational agent technology as coaches to help patients engage and better manage chronic health conditions:

> the aerial drones … led the way in removing people from danger … it really does create a whole new raft of operational capabilities … and that … new operational potential really is where the disruption comes from … there's been a number of social issues to overcome in terms of … pilots fearing the loss of jobs. That seems to have dissipated now in a manner of respects … If we start to utilise drones, we're not restricted to those constraints anymore and so, it really does disrupt. … unmanned systems … But if I've got my drones sitting in a warehouse and I deploy them as need be, it's really my industrial capability that comes into play in my ability to fight … (Firm #5)

> put … simply, we replace human health practitioners … So, instead of a patient with diabetes or congestive heart failure … seeing a practitioner who gives them dietary advice … exercise, and medication … about their condition, our virtual coach lives on your smart phone or your tablet, and she gives you information and education, and … helps you set goals around managing your condition … the patient interacts with (her), forms a therapeutic relationship with her, and … is better able to manage their condition … diabetes and heart failure and all the chronic conditions that exist … So, that's the problem … at the end of the day, we're not threatening their jobs, there's always going to be a need for a face-to-face practitioner, but there's just simply too many patients to support. (Firm #11)

Pattern 2 – an expansion in the scope of tasks

A second pattern apparent from the analysis of the data is that the adoption of disruptive technologies at the firm level has changed the nature of existing jobs and in doing so, expanded the range of tasks, creating the need for additional skills and content knowledge. For example, the manager of a large global defence supplier drew our attention to the scale and scope of change for radar operators and their skills as a consequence of the adoption of virtualisation and advanced radar techniques:

> there's too much change in the way that [radar] works … this radar can be multifunction, it can be an electronic warfare device, it can be a communications device … so the paradigm has changed … from an architectural system requirements point of view … you've … got something that has a whole lot more functionality and other capabilities that it didn't have before. (Firm #6)

We pick up on the challenges for employers and training providers in meeting these new knowledge and skill needs later. Additive manufacturing is used by Firm #6's engineers, whose skill set is now required to go beyond domain/discipline-specific knowledge, to include both knowledge in relation to material sciences and the practical skills required to use additive manufacturing.

Along similar lines, another manager drew attention to the need for the graduate engineers employed by the firm to develop skills in simulation software, which the firm utilises:

> they'll have programming skills … knowledge of digital design and hardware design, but in general they won't have the simulation-creation or even simulation-use skills … there's two levels of skills there: there's someone who can use a simulator instead of using a physical prototype and then there's people who develop the simulators. So they need to be able to look at a data sheet or specification from a piece of hardware and develop a model for it. (Firm #9)

However, as the change of pace in technology escalates, and the economy moves towards Industry 4.0 where the cyber-physical domains merge, the relationship between technology driving skills development or vice versa becomes less straightforward. This is largely due to the lack of certainty related to the use of emerging technology. A senior VET sector policy-maker identified the evolutionary changes occurring in determining competencies and skill sets, with learning models now defined by business rather than educational institution:

> over time as your business model matures and those technologies are embedded … the roles … become more defined and it's at that point where you … get defined competencies … occupations … and then qualifications … But doing it the other way round is difficult. (VET #10)

How disruptive technology may impact on skills is less obvious among small-to-medium enterprises (SMEs), especially smaller firms, in more traditional 'trade' sectors. It has been identified in earlier NCVER research that employers in the science, engineering, human resources and health professions are supportive of ongoing training for their employees and have processes in place to ensure it occurs, with the majority of this training taking place in the workplace (Clayton et al. 2013). While larger firms are able to make up for any deficiencies from VET courses or rapid changes in technology, this is not always possible amongst smaller firms. As some senior VET administrators note:

> the … dichotomy is that … you've got large companies … the big facilities [which] are great for in-house [training] but … the Australian dynamic, it's lots of small, sometimes single, sole trader, employers [who] might have one apprentice … [with] experience for the work that they're doing — the apprentice won't get the full range of learning that's required just in that situation. (VET #10)

> the idea that most of our people are going to end up working for your … huge conglomerates is misguided … in our region … 99% of all businesses are small medium. So therefore … the issue … is that the take-up of new technology and disruption … ain't going to occur in a lot of our traditional bread and butter [businesses] for 5 to 10 years, if then. (VET #02)

The current tension of providing just enough 'relevant' training versus providing fully qualified training for industry is exacerbated when it comes to disruptive technology, where the actual use and experience of technology in the workplace is less known.

Box 1 presents a case study of an enterprise actively pursuing the Industry 4.0 agenda. This company is building the capacity of its existing workforce while targeting potential employees with a specific portfolio of skills.

Case study 1: A company on the Industry 4.0 journey – REDARC

As companies seek to build new digital capabilities and pursue the Industry 4.0 agenda, they must acquire new knowledge and digital skills in support of this. One strategy employed to inform the Industry 4.0 journey is to map existing digital capabilities as a foundation for designing and implementing a digital capability-building strategy. This is what one company in South Australia has recently embarked upon.

REDARC is a South Australian-based company specialising in the research, design, development and manufacture of electronic products, in particular for automotive applications. The company specialises in energy management, charging systems, control systems and safety systems in vehicles.

REDARC employs 150 people in a state-of-the-art advanced manufacturing facility in Lonsdale, South Australia. The Lonsdale facility is a fully integrated site, incorporating sales, marketing, design, prototyping and automation of the electronics and manufacturing facilities, assembly, warehousing and distribution. A further eight employees, associated with the REDARC Group's Hummingbird Electronics, are based in an Innovation Centre in Newcastle, NSW.

REDARC owner Anthony Kittell says his company is actively pursuing the integration of disruptive technologies, principally in the areas of digitalisation and software-based engineering in the product-design process. The company is embracing Industry 4.0 technologies as a key business differentiator, with the aim of giving the company first-mover advantage in this innovation sphere. Notably, in its 2020 business plan, innovation and Industry 4.0 form one distinct pillar of the organisation's five strategic pillars, with $2 million budgeted to this area in 2018 (excluding direct equipment expenditure).

Industry 4.0 is seen as pivotal to REDARC's evolving focus on customising products and making low-volume high-value-added products. A unique advantage — and competitive edge — conveyed by Industry 4.0 extends from its focus on servitisation (which sees the manufacturing sector's innovating capabilities and processes shift from selling products to selling integrated products and services that deliver value in use (Seet et al. 2018)), which supports REDARC's intent to shift from 'widget' manufacture to being a solutions-based business. Through the digitalisation processes, REDARC seeks to achieve maximum transparency and seamless contact with customers 'right throughout the business so they can actually see into the business, see their stock, their product going through the process, understand their lead times, be able to put their schedules into our systems'. Customers are provided with maintenance and fault-analysis service data in near real time, and understand when and where problems are occurring and how to get these fixed — all streamlined, all on the screen in front of them.

Anthony Kittell believes that Industry 4.0 digitalisation technology has profoundly changed both the focus of the business and the way people work in the organisation. Key areas that have changed as a consequence of embracing Industry 4.0 technologies include:

- improved productivity and reduced labour as a function of:
  - machines talking to operators and vice versa (via computer programs), providing real-time information about process, quality, performance ratings etc.
  - software design capabilities making products instantly
  - configurable and self-analysis of products in real time
- rapid prototype tooling using 3D printing, reducing the process from three weeks to 24 hours, and from a cost of $1500 to $150
- teams coming together to 'look at how the product is assembled, look at all the different processes and look at seconds and how we can reduce that by smart design concepts. So products that clip together, software and testing and everything has been incorporated without the operator touching or doing anything'
- barriers broken down, achieving seamless working between different departments, for example, engineering and sales, manufacturing and engineering, manufacturing and quality. Digitalisation has done away with paper, all information is managed and shared in real time through computer systems
- sustained engagement following the release of products; there is a continuous improvement process, and an ongoing service and relationship with the customer over the life of the product.

Within an Industry 4.0 business framework, REDARC is seeking a workforce skilled in computer systems, electronics, mechanical/mechatronics, materials skills (how to optimise/reduce weight, advanced processes to protect electronics in harsh environments) and chemical engineering (a new focus for the organisation). Employees need strong STEM skills, the ability to analyse data and trending statistics, and to make decisions based on graphical output. IT literacy is important, as operators need to interact with and fix machines using connected computers.

REDARC has commenced preparing employees to become Industry 4.0-ready by engaging Fraunhofer IAO (one of the German-based Fraunhofer Institutes focused on disruptive technologies) to run dedicated sessions on Industry 4.0 capability-building, along with sending staff to conferences and engineers to Japan to study lean manufacturing and Industry 4.0-compatible machine lines. From an education and training perspective, Anthony Kittell considers that an Industry 4.0-specific qualification is less desirable than the application of an overarching Industry 4.0 lens across the core competencies of mechanical, chemical and electronic engineering (that is, highlighting the relevance of Industry 4.0 to each discipline and how to apply the technologies in real-world situations with machines that are Industry 4.0-compatible).

Also of importance is building awareness, both in industry and among training and education providers, of the potential for Industry 4.0 technologies and service-based approaches to transform the industrial base. There is a need for 'some sort of intensive fast track program for the people that deliver these courses so that they are actually brought up to speed with what's happening'. In terms of supporting SME uptake, there is a role for government programs, collaboration among leading businesses and high-performance case studies (noting that the CSIRO and government departments are doing some of this work already).

Anthony Kittell believes that the most important aspect of Industry 4.0 is its focus on world's-best customer service (and after-sales service) and the necessity of being 'close to your customer'. This is a key feature of the US Factories of the Future approach. REDARC has been successful in making this transition, thanks to its collaboration with Fraunhofer (which also undertook an Industry 4.0 audit of the organisation) and the role of the technology suppliers in running sessions to explain emerging technologies and associated opportunities. From a forward-thinking perspective, it is essential to examine how product road maps are geared to growth markets, by considering five to 10 years in advance where the opportunities lie and working towards this. In the last two years REDARC has given a great deal of consideration to designing a product and technology roadmap/diversification strategy geared to 2020 or 2025.

Research objective 2: Specialist skills versus generic skills for disruptive technologies

The second research objective sought to understand the extent to which specialist skills by comparison with generic skills are relevant to the implementation of disruptive technologies. Three main themes were identified.

- Overwhelmingly, higher education degrees from a range of engineering disciplines, as well as software development and computer programming, emerged as the main technology-related skills relevant to the adoption of disruptive technologies amongst established advanced manufacturers and start-ups.
- Larger businesses tended to have a more diverse skill base than start-ups, and identified trade-related skills as also important, with apprenticeships being the entry-level

qualification to employment. Amongst smaller enterprises, particularly start-ups, VET-trained staff were not perceived as relevant to disruptive technologies.

- The data also show that employers wanted potential employees to have more than technical skills, and that non-technical skills or soft skills like problem-solving, teamwork and creativity were just as, if not more, important.

We explicate these three themes below.

Theme 1

The importance of disruptive technologies when employing higher education graduates with technology-related skills, particularly those with higher-level technological skills, emerged as a recurrent theme among all interviewees.

The following quote from a manager of a supplier of services to advanced manufacturers draws attention to the nature of the tasks and their implications for skill sets:

> the skills needed to plan automation [and] to manage complex data sets are getting higher and so we see [an] unskilled workforce moving to paraprofessional and professional. (Firm #8)

Similarly, the owner—manager of a company that delivers services to advanced manufacturers, explained that 'what we see now is increasingly a lift in skill set within the actual production workforce and we see that's going to accelerate' (Firm #8). This is exemplified by a small advanced manufacturer who has increasingly employed engineers in its factory on the basis of their similar costs to production workers:

> Engineers are cheap these days … they're the same price as a production line worker almost … Half are operation line workers and half are engineers …They understand lean manufacturing … the line must never stop …They … act more like a robot than a person … they've been trained a certain way by [organisation name removed] and I've been the lucky recipient of their good training. (Firm #1)

As the REDARC case study shows (see Case study 1), some of these larger firms have started their own initiatives to prepare their workforce for Industry 4.0.

In terms of specific technology-related skills, employees from a range of engineering disciplines, including design, electronics and electrical, mechatronics, computer science/software, mechanical and chemical, were identified as important to technological change amongst all advanced manufacturers. Firm #2 identified that around one-third of its employees were engineers:

> Of that third about 25% are direct R&D and the balance are in … quality, manufacturing, engineering and even technical sales … materials skills are becoming more and more important … how to optimise, reduce weight, look at advanced processes to protect the electronics in harsh environments … now we are taking on chemical engineering people and they are also very good for quality, in terms of process control … computer systems, electrical electronics, mechatronics, mechanical and then materials … they are the key sorts of skills that we would employ. (Firm #2)

Another global provider of electronics solutions reinforced the importance of engineering skills/a specialist technical skill base, drawing attention to their technical workforce:

> We have everything from physicists, signal engineers, signal technologists, mechanical engineers, electronics engineers, industrial designers, manufacturer engineers, process engineers, technicians, production workers, procurement specialists, export specialists, planners … we … cover the whole gamut, including … IT specialists … ERP [Enterprise Resource Planning] specialists … software engineers. (Firm #3)

The need for software developers and computer programmers who can create the software needed for advanced machines, including robotics, or algorithms for artificial intelligence, also surfaced as a common theme amongst both advanced manufacturers and start-ups in the IT field. Both are underpinned by disruptive innovations, including artificial intelligence, the Internet of Things (IoT), mobile technology, and cloud computing. The following quote from an advanced electronics manufacturer illustrates this pattern:

> there's … more digital or software-based engineering … in … our product design process and … a lot of the IP… within the software … that has … been a major disruptor of the business … we are employing a lot more computer systems engineers or software programmers, rather than hardware engineers … we still need them but the numbers are starting to skew the other way … software now is … more important than the hardware. (Firm #2)

Given the increase in digital data, STEM and IT literacy are also seen as core requirements for employees, on the basis that, amongst other things, they underpin their ability to work with data and undertake data-based decision-making:

> STEM is … the key, in terms of being able to analyse data, make decisions based on … graphical output or trending statistics … being exceptionally IT literate is a key as well, because … the operator will need to either fix the machines or interact with the machine using … computers, software … then having an understanding of how that all comes together to create that linkage between the machine and the operator, and then the operator and the product, and the product and the customer, and then the customer and the dealer. (Firm #2)

Across firms, particularly start-ups, sales and marketing also emerged as highly desired skills, reflecting the need to attract customers:

> When you're in start-up, you've got this bundle of cash … you start with … and … you've just got to make sure that you don't go bankrupt, so everything stops, except that sale, get that cash in. (Firm #1)

Theme 2

Larger advanced manufacturers who employed staff without degrees spoke of the need for these workers to be equipped with a higher skill level too (for example, VET-qualified), and conversely, pointed to the lack of employability of staff who fail to obtain VET qualifications:

> we still take a number of young people directly from high school with no qualifications … to train them … for instance, I hired … a young person … and they'll undertake an electro-technology apprenticeship … an apprenticeship now is … the base level of where we want to train someone … we want to be able to … have a person go from an

> apprenticeship right through to advanced diploma and then … for instance, into a university degree … you hire someone as an apprentice, or to do a Cert. III, Cert. IV, and they are not able to complete it … what happens? … What task can you give them … they don't fit the requirements of the job, there's no job. (Firm #2)

In contrast, in most start-ups and smaller manufacturers engaging with disruptive technologies, VET-qualified staff were largely seen as unnecessary, with comments including:

> as far as ... the VET sector … I don't know about working with them. (Firm #11)

> [I'm] not necessarily in the VET space … I don't have a huge experience with TAFEs. (Firm #14)

> I'm not heavily involved in … the VET sector. (Firm #13)

> We very rarely deal with the technician. (Firm #9)

Theme 3

A third and final theme evident in the data is that employers seek staff equipped with more than technical skills. In particular, managers drew attention to non-technical skills and competencies, such as having a good attitude, teamworking, problem-solving and creativity. Specifically, employers were looking for employees whose knowledge ran deeper than utilising technology *per se*, and who possessed creativity and problem-solving skills to explore and deploy disruptive technologies effectively:

> mostly we look for great programmers … gun programmers … and by that, I mean programmers who can be really creative in finding solutions. (Firm #11)

> the key ingredient we're looking for in people in that [R&D] department is lateral thinking … with a practical and pragmatic slant. (Firm #4)

Other managers drew attention to the importance of attitude, passion, teamwork, people skills and continuous learning:

> we like … passionate people to work with us … strong technical skills in programming, ability to follow instructions, can interact and work with others, and attitude is key. Attitude is 100% the number one; if they have a crappy attitude, they will not work with any organisation very long, whereas if they are passionate … and don't have the technical skills … we will train them … but we can't change a lousy attitude into a good one; we don't have the energy. (Firm #17)

> Equally important is their … softer skills, their people skills and how they fit with the team … the attitude of learning and … continuous development, that's really important … the world moves on … I spend a lot of time studying and learning, to maintain my competency and … that's the attitude … I expect … to continually learn new capabilities. That continuous learning skill is critical. (Firm #5)

Conceptual skills also emerged as important, particularly to leadership positions; possessing these assists individuals to see how all the parts of the organisation work together to achieve organisational goals.

The need to develop both technical skills and non-technical or soft skills is also recognised in the VET sector:

> they request both … but we have seen a lot more soft skills being requested … when they request us … [to] recommend graduates … they look for people who are strong communicators … can write a good report … have no problems standing up and speaking in a meeting, and … can problem-solve. (VET #04)

There has also been an increased awareness that, in relation to disruptive technology, many technologies are not restricted to one or two trades and may apply across many jobs. Consequently, in line with the move towards Industry 4.0's fusion of cyber-physical domains, some initial attempts have been made to push for training to be available across multiple trades:

> our executive … would like us to start assisting the trades to better embrace that technology, because there's a … fear … is the job of fabricator safe, is the job of welder, or the job of machinist a safe job? … we try and work in an interdisciplinary manner. So we run our final year as an integrated project, so they have to use all the technology, they have it available, to produce a final product … like our large format CNC [computer numerical control] machine … built in house by students over 12 months … that gives them the experience of both using the technologies to do it, and producing the technologies themselves from a design standpoint … that requires electronic engineering, electrical engineering, mechanical engineering all working together … moving from purely the design side and a bit of prototyping, which is what our core business was, more towards … modern technologies, more contemporary methods of manufacture. (VET #17)

Research objective 3: Technology innovators' and employers' perspectives on skills acquisition and development for disruptive technologies

The third research objective focused on the extent to which consensus exists between the technology innovators and the end-use employers when it comes to skills acquisition/development for disruptive technologies. There appears to be consensus that the types of skills needed vary according to the nature of the technology; for example, the developer of virtual prototype-simulation software (Firm #9) identified two levels of skills needed by design engineers to utilise the software:

- skills in using the software
- skills to develop a model based on customer specifications.

The supplier of the software provides training to customers, who are other design engineers, as part of a package of services. The training consists of instruction on the use of a virtual simulator rather than a physical prototype, and instruction on how to develop a simulation model based on a data sheet or specification from a piece of hardware.

In terms of skills and training, although there may be general consensus in industry about where the disruptive technology trends are heading and that both industry and the VET sector are aware of technological trends, there is often uncertainty in terms of specific technology. Agreement on the specific skills needed and how the training is delivered also differs, as does which industries would benefit most and what the appropriate delivery timelines are. This is illustrated in the quotes below from VET providers attempting to pre-empt training in additive manufacturing and broadband technology:

> We bought a 3D printer probably … 5 or 6 years ago … it's been … used twice. There's a disconnect between what we bought it for … for our construction industries … and prototyping, which we thought we'd be doing … probably [it] was too early in the piece … 3D printing definitely is something that we should be looking at … But… its application would be in those 5 to 10% of our businesses that do a lot of prototyping and customised type work. (VET #01)

> We found with the NBN we geared up probably 2—3 years ago thinking, oh, NBN we'll get there ready to go, it's just starting to roll out now. So in terms of that lag lead time, you get a bit interested. The interesting thing I suppose about disruptive technology to us and from a TAFE point of view, the actual people that are doing it will probably be the same but it's just what they're doing that's different. (VET#02)

Sometimes the drive to change and adopt the use of disruptive technology does not come from industry or the VET sector, but from the students. As illustrated in the excerpt below, drone technology (which is now more accessible due to lower costs) has become quite ubiquitous among hobbyists, resulting in its inclusion in a VET sector course:

> we've done some work with our surveying students and … they're starting to use a lot of drones … our courses … need to be doing that … to enable them to use drone technology to do surveying. (VET #01)

Research objective 4: Barriers to VET students' and graduates' skill acquisition and their ongoing skill development in the context of disruptive technologies

The final research objective examines the barriers to VET students' and graduates' skill acquisition and development over the next five to 10 years. The barriers to employee skill acquisition fall into two categories:

- employee skills gaps, with managers drawing attention to technical and non-technical skill gaps among both VET and university graduates
- shortages of local private and public training providers with the capacity to deliver training in the skills required for the new technologies.

We noted earlier the importance of STEM skills to enable employees to engage with disruptive technologies. However, based on our interviews with firms utilising some form of disruptive technology, employers believe that some employees lacked sufficient literacy, numeracy and STEM skills, which has adverse implications in terms of workers' ability:

> the problem is that disruption is outpacing our education system … literacy and numeracy … [are] actually going [backward] … what we are having to do is run our own internal training sessions for all of our young people … taking engineering staff off the job to actually train our younger staff because they are not coming out of the school system with the right level of STEM … we run a session … every Friday afternoon for two hours with our apprentices, it's voluntary … it's in work time, basically coaching them to get through a trade … because I've had students failing subjects at TAFE and … that's a … major issue for Australia for our competitive advantages about talent. (Firm #2)

A manager of a supplier to defence also draws attention to gaps in employees' STEM skills, in this case, physics, and its adverse implications for product performance:

> underpinning a lot of that is basic physics … there were some students at times [who] … hadn't had the basic physics and that matters … because they perhaps do not understand centre of gravity … they'll make suggestions which would cause our equipment [to] … topple and fall and hurt people. (Firm #5)

Other STEM-related skill gaps were in computer programming/coding skills (three firms), big data and analytics (four firms) and Industry 4.0 (two firms).

Employers also discussed the job-readiness of graduates as another skills gap, although this varied depending upon the expectations of specific employers. At one end of the spectrum, employers believed that the education system should equip graduates with all of the skills necessary for entry into jobs or careers; or in the words of managers 'give us a finished package' (Firm #4) or 'at day one be absolutely perfect'. Employers such as these appear to be reluctant to hire recent graduates and to invest in on-the-job training. A manager of a small firm notes:

> if I recruit a university graduate … it would be someone with a photovoltaic engineering degree, but this guy that we've been using has got industry experience … which is … important, for a small business like us. We can't have a graduate here making mistakes … You've got to hit the road running … I pay a bit more for it. (Firm #1)

Another manager spoke of deficiencies in VET graduates' practical/work experience, with 'a shortage of people with advanced learning in technical skills', and believes that 'industry needs to take responsibility for the practical application' (Firm #4). As with other larger employers in the study, the firm is increasingly providing opportunities for students, recognising that it, in turn, benefits from access to the students' digital knowledge base:

> we're increasingly sourcing students to do projects for us … help give them the skills but also as a resource to people who are aware of all of the latest technologies, they have all of the skills and smarts when it comes to sensors, when it comes to Internet of Things, so our associations with the universities and access to those kind of students have become increasingly important. (Firm #4)

At the other end of the spectrum are managers who perceive educational institutions as providers of core discipline knowledge, with industry responsible for employee development:

> part of my job is to train them, develop them as people … It's an easy trap to fall into … particularly in a vocational sense, to expect them to come out, 'job ready' … The university courses could never possibly cover all that … you should be teaching … the more generic … student learning … the core mechanical engineering properties, core electrical engineering properties … other domains … giving the students awareness of other disciplines … I don't expect a person to walk in here as a project manager … unless you've had some experience … I'm not overly keen on people being taught as a system engineer. You become a system engineer because you work across multiple disciplines, multiple projects and you've got that experience. (Firm #5)

The second major barrier to VET student and graduate skill acquisition and development is the shortage of local specialised private and public training providers able to deliver training in the skills required for the new digital technologies and reinforces findings from earlier research (Callan 2006; Clayton et al. 2013; Service Skills Australia & University of Ballarat 2009; Toze & Tierney 2010). As noted in the preceding sub-section, some interviewees drew attention to deficiencies in the STEM knowledge of employees at both the VET (for example, Firm #2) and university (Firm #5) levels, which also has implications for educators in these sectors.

Managers spoke of difficulties in not only identifying specific digital skill sets, but also in finding public and/or private providers to provide the knowledge, education and training in specific disruptive technologies:

> Big data analytics, data scientists for example. We're not training anyone in it … the research that we're doing is … at MIT [Massachusetts Institute of Technology in the US] … there is no one here … in America you can't hire one, they don't exist. Everyone's soaked up and in Australia, if there was any, they would be in America. … There are some universities that obviously research in this area and leaders in their own domain on a global basis so definitely the university sector has a role to play in leading that. But it's also sharing that, connecting that into industries so that they can see it, understand it. (Firm #8)

Along similar lines, another interviewee highlighted a lack of industry experience amongst trainers as a barrier to the delivery of Industry 4.0 training:

> to get … the best training outcomes, it's good to have people with real-world experience and knowledge … the training industry is behind the eight ball … I don't see those people out there. (Firm #2)

Another manager concurs, identifying shortcomings amongst education providers, arguing 'no one at TAFEs, no one at universities is teaching the stuff that's needed to be known at the moment' (Firm #8). He goes on to pinpoint deficiencies at the individual level of the university or TAFE lecturer, where the domain knowledge resides, claiming that this often doesn't incorporate the latest information that needs to be taught. He also highlights shortcomings at the industry level, specifically in manufacturing, where smaller manufacturers, who are becoming increasingly prevalent, need to take a proactive role in forecasting future trends and demands for skills.

Turning to the question of how the VET sector in general and providers in particular could better address firms' education and training needs, interviewees from small firms argued that a VET workforce, and by extension, VET providers, were not perceived to be relevant to their skill needs. In contrast, respondents from larger enterprises pointed to opportunities for VET and/or universities to provide training for disruptive technologies, and for educational providers — from schools to higher education institutions — to better prepare students with STEM and non-technical soft skills. In terms of disruptive technologies, the evidence from the case study research reveals the need for an Industry 4.0 qualification for a few selected staff, with an Industry 4.0 training module for the firm's wider workforce:

> an Industry 4.0 apprenticeship … that's a very specific qualification which we would have interest with but only for a select few employees … a top-up, not a qualification but a top-up module for Industry 4.0 is a must, so the ability for either university [name removed] or TAFE or a private provider to be able to come in and offer our employees an Industry 4.0 module, or at least … an overarching … base qualification … is pretty important. (Firm #2)

However, providing education and training is not straightforward, since, as noted above, a theme cutting across interviewees was the difficulty associated with sourcing qualified trainers with the requisite experience. Managers pointed to the need for trainers and teachers at all levels to upskill: undertaking fast-track training to acquire the necessary knowledge and understanding of Industry 4.0, with governments and industry a crucial part of this process, as the following quote from the case study research highlights:

> we need some intensive fast-track program for the people that deliver these courses … from VET through to postgraduate levels … an awareness program of what Industry 4.0 is and why it is important and how we educate our industry sectors to take this on board … it's government programs as well, through departments of trade or industry … get experts in from the world's best … proponents of the subject matter … and lecture us, deliver programs. And collaboration, amongst businesses that are doing it well … highlight case studies.
>
> (Firm #2)

Thus, there is a role for government programs, collaboration among leading businesses and high-performance case studies to build awareness both in industry and among training and education providers of the potential for Industry 4.0 technologies and service-based approaches to transform the industrial base, particularly amongst SMEs. There is some, albeit limited, evidence indicating that a few larger firms are adopting this approach. For example, one firm manager states:

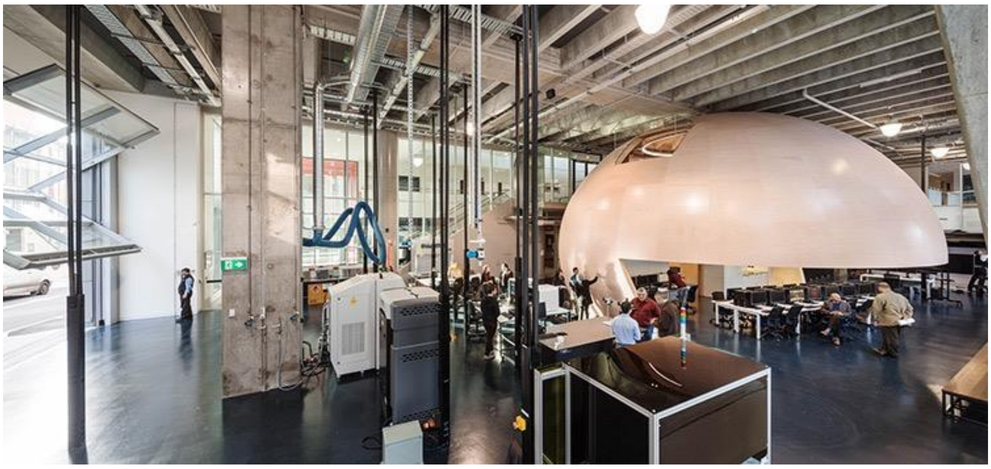
> our people are upgrading their skills externally and through us in training courses … but … also we leverage local industry capabilities like in additive manufacturing … and in some cases, we will leverage our parent company to bring training to Australia and provide that training … we usually invite the universities along to participate in it as well. (Firm #6)

An example of how this is occurring in Australia is illustrated by the AMDC/Factory of the Future Testlab case study at Swinburne University of Technology, shown in Box 2.

Interviewee (Firm #8) concurs and draws attention to the changed nature of learning and training alternatives to meet these needs (for example, online courses, seminars, experts in specialised areas):

> Learning new things quickly, much quicker than a four-year degree, is needed. The challenge in industry now is how do we learn this stuff? We're doing online … going to targeted seminars. We're working with experts in specialist areas.

Case study 2: Building digital skills and capabilities in VET – Swinburne University of Technology



Building digital capability and capacity at the company level requires a digitally competent workforce. With a growing body of research indicating that automation and artificial intelligence have profound implications for the demand for specific digital competences and skills, Swinburne University of Technology has implemented Australia's first Industry 4.0-focused Apprenticeship Program.

The Swinburne University of Technology Advanced Manufacturing and Design Centre (AMDC) is a state-of-the-art facility providing strong links across the higher education, research, vocational training and manufacturing sectors. The centre houses Swinburne's 'Factory of the Future' facility. The factory contains a series of co-located studios, each with a specific function. These include a:

- 3D Visualisation and Design Studio: featuring advanced visualisation tools that allow for intuitive real-time interaction with realistic 3D imagery
- Rapid Manufacturing Studio: equipped with advanced additive manufacturing tools, which facilitate conversion from digital concepts to metal, plastic or ceramic prototypes
- Advanced Inspection and Machining Studio: advanced machining capability, combined with state-of-the-art inspection equipment for developing high-quality components
- Biodevice Innovation Studio: combines electronics, optics, chemistry and biomaterials-handling with rapid prototyping to produce innovative medical devices
- Design for Resource Efficiency Studio: for the design, development and assessment of recycling and manufacturing processes to maximise resource efficiency.

The centre provides researchers and students with the opportunity to use the latest manufacturing and design techniques and technologies. VET courses provided by the centre range from Certificate II in Engineering Studies to Advanced Diploma of Engineering Technology (with various specialisations), Advanced Diploma of Electronics and Communications Engineering and Advanced Diploma of Computer Systems Technology. Further pathways are available into higher education, including bachelor degrees through to PhDs. The Swinburne VET team provides full-time standard courses as well as customised training modules addressed to emergent technologies. The team consists entirely of engineers by profession, all of whom have worked in the industry and have an intimate knowledge of industry trends.

The Swinburne University AMDC has recently partnered with Siemens on a major collaboration to access leading-edge technology that allows products to be designed and developed in a virtual environment without having to build physical prototypes. Swinburne's Factory of the Future is the key platform for developing and teaching about Industry 4.0 technologies.

The Manager of Engineering & Advanced Manufacturing at Swinburne University, Ms Shanti Krishnan, highlights the university's widespread reputation for being at the cutting edge of industrial change and its expertise in Industry 3.0 automation and mechatronics. The Swinburne team is highly conscious of closures in the automotive industry and the general manufacturing downturn and has been actively seeking new opportunities to re-establish the university's relevance to industry and in particular, the manufacturing sector, where Swinburne University has a history of industry-based learning. Ms Krishnan believes that the team is building on existing strengths in Industry 3.0, and embracing the disruption of digitisation by extending into Industry 4.0 is more of an 'evolution than a revolution' for the team.

The Swinburne University VET team recently collaborated with employer organisation Ai Group and Siemens to develop the Industry 4.0 Apprenticeship Program. Nineteen students participated in the trial, culminating in a Diploma in Applied Technologies. Training was provided in cutting-edge manufacturing technologies, including 3D metal printing, machine vision and virtual reality applications. These skills are considered necessary to enable graduates to respond to disruptive technologies in all industries.

Challenges of disruptive technologies for VET

The research has highlighted a number of barriers that the VET sector experiences in developing the skills and preparing their students more effectively for emerging and disruptive technologies. These are briefly categorised into the following three issues:

- *Weak industry—VET sector—university linkages and collaborations*: this affects the ability to ensure that workers have the knowledge and skills (both technical and soft) required by employers. While there have been calls for closer integration between the VET and university sectors (BCA 2017; Scott-Kemmis 2017), this may be more easily said than done. As a VET sector respondent noted:

  > I've pushed the idea before, it's … finding our way through both the university and TAFE bureaucracies to make that happen … we would love to be doing some of that work with the universities, because the university's strong point has always been the theoretical … TAFE's strong point has always been the practical … That seems complementary to me, it's not competition. (VET #01)

- *Internal resourcing and structural constraints in the VET sector*: significantly fewer resources have been invested in the VET sector in recent years (for example, work or role intensification among trainers, scarcity of time, rigid structures, non-supportive organisational climates, inadequate budget allocation, outdated policy or work instruction, obsolete resources or equipment, lack of recognition and rewards, and limited availability of specialised VET practitioners (Clayton et al. 2013). This, along with continual restructuring, has hampered the sector's ability to properly plan and execute these difficult changes while preparing itself and students for disruptive technologies:

> our issue is definitely time for training … [and] getting staff is a very difficult one … there’re a lot of overheads … which make it very difficult to get lecturers … and it’s not a job I would actually recommend to anyone … I don’t know where we’re going to go for [staff] in the future, the more technology we get the more we’ve got to train and it’s never-ending. (VET #07)

- *Limitations of training packages*: there is a strong view among VET sector respondents, especially those involved in delivering training, that training packages are limited in their capacity to assist VET teaching staff to train and prepare students for the rapidly changing disruptive technologies:

> So within training packages, the units and modules … limit us in what we can do and how we can interpret that … for example, if I want to incorporate something, and I search my training products, it’s limited because they will say in this training package, you can only bring in one extra elective and that has to be within this context. So I can’t teach entrepreneurialism to my engineering students because the training package has nothing in it. (VET #04)

> There is no way that training packages have helped the delivery in the IT area in any way shape or form … it’s an assessment system … a means of auditing and controlling the process. The outputs of the training don’t facilitate actual delivery at all in any way shape or from … It’s almost [devoid] of delivery strategies.
>
> (VET #05)

> the big issue … is we’ve lost the ability to have prerequisites in our training package … students no longer want to start at the lower levels, they want to come straight in at a higher level and … we can’t stop them now due to no prerequisites … we can advise them that, ‘Well this is a higher level to [the] knowledge you have; maybe you should do a low level’. [But] You can’t stop them from doing it and they go into the high level but it’s … too difficult for them or it’s not really what they want to do. (VET #07)

Conclusions and implications

Concerns about automation may be premature – it is too early to be definitive about the human–machine interface.

This report has provided an assessment of the implications of disruptive technologies for future skill development and for the VET sector from the perspectives of innovators (technology producers) and industry (technology users), as well as VET educators, managers and policy-makers. The findings from the report provide a foundation for considering the likely implications of disruptive technologies for VET policy and planning. Concerns about a sharp decline in the demand for routine tasks as a consequence of automation and robotics need to be tempered by what is actually taking place in different industry sectors and the likely pace of change, given these realities.

Most of the stakeholders interviewed agree that it is timely to develop a detailed understanding of the impact of disruptive technologies on the demand and supply of qualifications and skills in both the VET and university sectors. This is a challenging task, one requiring a commitment to gathering multiple sources of evidence over time. Reliance on modelling the demand for skills and qualifications will be difficult in an environment where disruption confounds results. This report has sought to illustrate the value of gathering evidence directly from key stakeholders in order to capture the complexity of the challenges that face the VET sector in response to technological disruption.

While the literature review demonstrated the divergent views on the extent to which disruptive technologies will create or lead to the loss of jobs or specific tasks (Brynjolfsson & McAfee 2014; Frey & Osborne 2013; Productivity Commission 2016; Arntz, Gregory & Zierahn 2017; Bakhshi et al. 2017), this research indicates that disruptive technologies are likely to have highly differentiated impacts on firms, these impacts depend on a firm's size, their stage of development, and their absorptive/innovative capability and capacity. This is illustrated by the varying impacts of disruptive technologies as described by the research participants. For example, automation and virtualisation may contribute to higher productivity, with fewer workers required and/or the reduction or elimination in the need for certain types of occupations or tasks. However, in other firms, robotics enables the removal of employees from dangerous tasks, while artificial intelligence substitutes for employees, (partially) filling identified workforce gaps. Ultimately, a wide range of factors drive the decisions to automate, implement robotics or adopt artificial intelligence, beyond the fact that it might be possible, given existing technologies to automate routine tasks (Frey, et al. 2016).

The existing research identifies three alternative concepts or scenarios of automation to describe the relationship between workers and machines. Supporting international research, we found it is too early to be definitive about the human—machine interface (Schröder 2016). Importantly, we find no evidence of human labour playing a subordinate role in the production process ('the automation scenario'; (Buhr 2015)). Instead, we suggest that human labour and technological applications can often be complementary in this process (or 'the hybrid scenario'). This is not inevitable and will involve human agency in determining the nature of the human—machine interface in particular settings, taking account of both social and economic factors.

Our results align with recent research that indicates that disruptive technologies such as 3D printing are changing existing jobs in established firms, creating the need for current workers to acquire new skills in order to carry out additional/new tasks. These workers require different, often higher-level, technical skills to work with new technologies, with this requirement meaning investment in skills development (Sandström 2016). However, this may not always be the case, as some disruptive technologies may lead to dramatic declines in demand for some skills, while the demand for related skills is increasing. The net impact can be small if those displaced from one occupation are able to gain the skills necessary to transition to a related occupation. This situation highlights the complexity surrounding attempts to assess the impact of technology on the demand for skills and qualifications and is a significant challenge for the VET sector.

The findings of this study underscore the importance of particular workforce skills (e.g. information and communication technology (ICT) skills and non-cognitive skills that require perception and manipulation) (Frey et al. 2016) for workplaces implementing disruptive technologies, including VET qualifications for entry-level positions through to graduate and postgraduate qualifications.

In line with international studies (Erol et al. 2016; Hirsch-Kreinsen 2016), we find that soft or people skills, including teamwork, problem-solving, continuous learning and creativity also emerge as integral to the uptake and implementation of disruptive technologies. However, the findings indicate that gaps in employability skills and STEM-related skills — reflected in deficiencies in the level of underlying STEM knowledge of some employees — are also barriers to the utilisation of digital technologies.

A shortage of private and public training providers with the capability to deliver the requisite education and training emerged as a further barrier to addressing skill gaps. The findings also indicated that addressing barriers is not straightforward, especially in the public VET sector, where internal resourcing and structural constraints and the limitations of training packages apply.

Research limitations

While our research adds to the limited number of studies in the Australian context, with most of these having been conducted by consulting firms or industry bodies (Chartered Accountants Australia and New Zealand & Deloitte Access Economics 2016; Raine & Anderson 2017), it is important to note that we interviewed people who are more likely to have insights into disruption, and the research is based on a relatively small sample of senior business and VET sector respondents. Others with less knowledge of the potential of disruptive technologies may find their impacts more difficult to manage and the benefits of applying disruptive technology more difficult to realise. They are less likely to recognise a need for particular digital skills and enabling competencies, yet may soon find these are required in order to remain competitive. Indeed, national policy is seeking to accelerate the uptake and diffusion of digital technologies, which will increase the demand over time for skill sets and qualifications in support of the Industry 4.0 agenda.

This research project has focused largely on firms in the advanced manufacturing and information technology sectors. While these sectors are facing the imminent effects of technological disruption, not all sectors in Australia will be affected in the same way. We note that a focus on these two sectors, along with differing rates of absorptive capacity in the sectors and within firms, may overstate the problem (Hordacre, Spoehr & Barnett 2017; Plattform Industrie 4.0 2017; Productivity Commission 2016).

Implications for practice and ways forward

The following points suggest some future strategies for the VET sector, industry and governments in Australia as a result of this study.

VET courses

- One of the effects of disruptive technologies is the likelihood that a range of routine, and, increasingly, some complex tasks, will be subject to automation. While this is likely to change the nature of existing jobs, it is also likely to profoundly impact on the demand for skills and qualifications over time, requiring some offerings to be modified, some abandoned but others created. What is clear is that the demand from firms for higher qualified employees is set to increase in response to the technologies and business models that are being deployed (Wisskirchen et al. 2017).
- This gives rise to the need to review VET course offerings and the technical capabilities of teaching staff in support of the uptake and diffusion of disruptive technologies. Existing demand will be insufficient as a guide to future demand, given the expected changes. This will require the VET sector to have access to specific industry intelligence on the skills that digitally and technologically mature companies require now and over the medium term.

Generic skills

- Besides developing the technical skills and knowledge relevant to disruptive technologies, it continues to be important to promote the development of 'generic' or soft skills as essential elements of employment in a digital age. Related to this is the need for a clear statement on the contribution of so-called 'soft' skills to the successful uptake and diffusion of disruptive technologies and the associated business models.
- This aligns with emerging research that recognises that unique human skills are not easily replicated by artificial intelligence and other disruptive technologies. In particular, 'soft' skills, which encourage and facilitate creativity, abstract and systems thinking, collaborative activity, complex communication, and the ability to thrive in diverse environments (Brynjolfsson & McAfee 2014; Raine & Anderson 2017), prepare workers to be flexible and cope with the rapid workplace changes that result from disruptive technologies.

Cross-industry initiatives

- The recent moves by the Australian Industry and Skills Committee and the VET sector's industry reference committees towards developing cross-industry units, skill sets and qualifications, and their adoption across multiple industries should be applauded and extended (Skills Impact 2017).
- The disruptive cyber-physical technology of Industry 4.0 is yet to mature and will see ongoing development, which means that the acquisition of relevant skills will not be restricted to the time spent on VET courses. Hence, there is a need to better

understand and implement pre-VET exposure to Industry 4.0 skills and knowledge in the school years, which will help to prepare potential VET trainees for these technologies (National Academies of Sciences & Medicine 2016).

Educating for disruptive technologies

- While the VET sector is already conducting comprehensive research into issues related to training packages, additional studies are needed because, as the pace of adoption of disruptive technologies increases, so too will the need to adjust Australian VET sector policies and practices. For example, in terms of training packages, one solution that needs more widespread consideration is that advocated by Misko (2010) — the use of accredited courses, which is a viable option in the short-term while the long-term changes are picked up in the training package in due course.
- Another solution may involve a significant shift away from existing approaches to articulating and meeting training requirements. The new industrial revolution is disrupting the way education and training is delivered, by moving away from mass education to a more diversified, just-in-time, micro-credentialing education eco-system (Crow 2017; Feenan 2016). The VET sector will need to take this into account when developing offerings that are both responsive and appropriate. Recent research indicates that around one-third of technology analysts and industry experts in the US had no confidence that training and education would evolve rapidly enough to match demands by 2026 (Raine & Anderson 2017).

Skills updating and lifelong learning

- To cope with the changes introduced by disruptive technologies, the VET sector and employers need to work together to support the continual updating and upgrading of the skills of VET graduates after they have qualified and entered the workforce, by developing systems that support lifelong learning. It is not realistic for firms to expect their fully qualified VET employees to have no need for further skills and knowledge development. Hence, firms will need to step up their efforts to train and retrain workers, with the VET sector playing a complementary and reinforcing role as a provider of lifelong learning (Raine & Anderson 2017).
- As the REDARC case study illustrates (Case study 1), employers will need to invest substantially in ongoing capability-building among their employees to meet the challenges of Industry 4.0. The VET sector, in addition to catering for current students and apprentices, needs to work with industry to build systems and capabilities to facilitate ongoing and lifelong learning (for example, through flexible micro-courses) to ensure that the skills of VET graduates or alumni are upgraded (BCA 2017). As part of these initiatives of continual skills upgrading, new pathways for VET graduates to move to university degree programs (as illustrated in the AMDC/Factory of the Future Testlab case study at Swinburne University of Technology; see Case study 2) should also be explored, with the aim of upskilling the workforce to operate and maintain increasingly complex cyber-physical systems (National Academies of Sciences & Medicine 2016).

Skill implications of Industry 4.0

- Finally, as we have noted, Industry 4.0 has implications beyond the VET sector. It is recommended that a review of the implications of the Industry 4.0 agenda for the demand for skills and qualifications in Australia be initiated. This should include sectoral consultations with companies with different levels of technological maturity. It should also be informed by international comparisons involving nations where the Industry 4.0 agenda is well advanced.

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Appendix A

Interview methodologies and sample characteristics

Following the qualitative research practice of Brown et al. (2009), interviewees were asked to describe and elaborate on these questions and give specific examples in order to ensure that the interviews were anchored in lived experience, not what managers might feel obligated to state (Hunt & Boxall 1998).

Each participant provided permission to the interviewer for the interview to be digitally recorded.

Individual responses were transcribed and checked for accuracy with the interviewee before data coding and analyses commenced. Inductive coding was used (Saldaña 2009) to draw out the main themes and patterns, and initial findings were incorporated into the VET sector interviews. Responses were combined with other interview data and overarching themes identified.

Table A1 Key characteristics of the sample firms

Firm #	Industry/ technology	Location	# Employees	Remarks
1.	New energy supplies and technologies	SA	Medium (20–199)	High technology firm
2.	Advanced materials; new energy supplies and technologies	SA	Medium (20–199)	Australian owned MNC
3.	Advanced materials; advanced manufacturing	SA	Large (200+)	Australian owned MNC
4.	Advanced materials; advanced manufacturing	SA	Large (200+)	Australian owned MNC
5.	Advanced materials; advanced manufacturing	SA	Large (200+)	MNC
6.	Advanced materials; advanced manufacturing	SA	Large (1000+)	MNC
7.	Advanced materials; advanced manufacturing	SA	Micro (<5)	Technology services
8.	Advanced materials; advanced manufacturing	SA	Micro (<5)	Technology services
9.	Advanced manufacturing	SA	Small (10-20)	High technology spin-off from MNC
10.	Cloud technology; Internet of Things; Artificial intelligence and machine learning	SA	Medium (50–200)	High technology firm
11.	Cloud technology	SA	Small (5–10)	University/ research institute spin-off
12.	Cloud technology	SA	Micro (<5)	Start-up

13.	Cloud technology; advances in computing power and big data	SA	Micro (<5)	Start-up
14.	Cloud technology; mobile internet	SA	Small (~20)	High technology firm
15.	Cloud technology	WA	Small (11–50)	Technology and professional services
16.	Advanced robotics and autonomous transport	WA	Large (200+)	Technology & professional services
17.	Cloud technology; advances in computing power and big data	WA	Micro (<5)	Start-up
18.	Advanced materials; advanced manufacturing; Internet of Things	WA	Large (5000+)	Australian owned MNC
19.	Mobile Internet; cloud technology	WA	Micro (<5)	Start-up
20.	Cloud technology; crowdsourcing, the sharing economy and peer-to-peer platforms	WA	Micro (<5)	Start-up
21.	New energy supplies and technologies	WA	Micro (<5)	Start-up
22.	Advanced manufacturing; Internet of Things; advanced materials	SA	Micro (<5)	Start-up
23.	Advanced manufacturing; Internet of Things	Vic.	Large (2000+)	MNC

Note: MNC = Multinational Corporation.

Table A2 VET sector respondents

VET #	Position/ technology	Location
1.	Lecturer/lab manager; advanced manufacturing and 3D printing	WA
2.	Senior TAFE manager	WA
3.	CEO private VET provider	WA
4.	Head of programs; advanced manufacturing and 3D printing	WA
5.	Lecturer; mobile internet; cloud technology; IoT	WA
6.	Lecturer; cloud technology; advances in computing power	WA
7.	Lecturer/lab manager; cloud technology; advances in computing power	WA
8.	Senior VET policy director	WA
9.	Lecturer; advanced manufacturing and 3D printing	WA
10.	Industry training advisory bodies representative; VET policy consultant	WA
11.	VET policy manager	WA
12.	Industry skills council representative	ACT/ WA
13.	VET policy manager	WA
14.	Industry apprenticeships and traineeships manager	WA
15.	Senior TAFE manager	WA
16.	Senior TAFE manager	SA
17.	VET program manager; advanced manufacturing and 3D printing	Vic.
18.	VET lecturer and higher education coordinator	NSW

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