Flinders University
Australian Industrial Transformation Institute

Making waves

Enhancing the enterprise journey towards Industry 4.0 through engagement & dissemination

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Australian Industrial Transformation Institute

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Industry 4.0 maturity and readiness

Small and medium-sized enterprises (SMEs) tend to face greater external uncertainty and evolve more slowly than larger businesses due to limited knowledge, human and financial resources. Thus, from the outset, many SMEs experience reduced ability and willingness to adopt innovative technologies.

SMEs tend to rate relatively low in terms of Industry 4.0 maturity and readiness; moreover, the step from level 0 (novice) to level 1 (advanced beginner) is much steeper than transitions between other levels. This signals the need for a concerted shift in individual mindset and organisational culture.

International research shows that SMEs are interested in the capacity of Industry 4.0 to drive cost reductions and improved time to market, and to address human resource issues such as labour shortages. However organisational barriers exist relating to *economics* (e.g. lack of monetary resources and clearly defined economic benefit); *culture* (e.g. lack of trust between partners, low-level management support/acceptance by employees, risk aversion); *competency/resources* (e.g. low level skills/technical knowledge, coordination effort, factory layout constraints*); legal reasons* (e.g. data security, bureaucracy, restrictive laws and regulations); *technical reasons* (concerns about system reliability, difficult interoperability/compatibility); and *implementation processes* (e.g. required time and changes, difficulties in demand forecasting).

Australian research indicates that SMEs struggle with Industry 4.0 transformation due to lack of skills (especially non-technical skills such as workforce readiness for change) and low-level digital capability to manage data for internal and external operations. External collaboration and involvement in Industry 4.0 skills and knowledge training and research is recommended.

SME-University engagement

Developing networks and collaborating with universities can be an effective way to advance SME Industry 4.0 maturity. However, there are several factors to consider in relation to industry readiness and motivation to engage with universities.

Organisational characteristics that serve as necessary precursors for SMEs to engage with universities include *readiness* (identified need for change in the organisation, willingness to consider new ideas and how these will work in practice); *importance* (recognising the potential impact of making change including risks and opportunities); and *confidence* (belief in the ability to make prudent decisions and having the capability to successfully implement them).

Industry drivers for engagement with university include *necessity* (e.g. meeting government and legislative policy); *reciprocity* (e.g. ability to attract funding for projects, accessing students for internships/hiring); *efficiency* (e.g. commercialising for financial benefit, achieving cost savings, improved competitiveness); and *stability* (e.g. business growth, access to new knowledge, solutions to problems).

Potential benefits of university-industry engagement can be *economic* (more cost effective than internal R&D, access to public grants and funding, improved products and services); institutional (exposure to leading edge technologies, access to wider network of research expertise); and *social* (reputational advantage and credibility, stimulating and fulfilling). However,

these benefits need to be weighed against **potential risks**, for example reduced control over commercial information and conflict with organisational mission.

SME-University engagement in the context of Industry 4.0

SME engagement with Industry 4.0 technology builds across a series of stages, progressing from *skill and knowledge acquisition* to *persuasion* about the value of the technology, to making the *decision* to proceed, to *adopting* the technology, culminating in *routine use* of technology.

The ‘4E’ framework proposed by Farkas, Jette, Tennstedt, Hayley, and Quinn (2003) provides four dissemination and utilisation strategies designed to progress knowledge acquisition into the realm of practice (knowledge translation/utilisation). These strategies outline goals and methods relating to *exposure*, *experience*, *expertise* and *embedding* a new approach such as Industry 4.0. Effective dissemination methods need to be designed with the end-user in mind, preferably with input from the end-user to ensure that outcomes will address ‘adopters’ needs. Research indicates that **hands-on experience with technology** through trialling in a technically supported environment is a key facilitator for technology adoption.

Mechanisms for industry engagement, collaboration and knowledge transfer with external stakeholders/universities can be *formal* (e.g. contract agreements, venture investment, technology licensing, patent purchase) or *informal* (e.g. trade fairs, conferences, seminars/workshops, sharing facilities). While both forms of interaction are valuable, research has shown **informal external collaboration to be of particular benefit** in enhancing the innovation performance of hi-tech manufacturing SMEs.

AITI-SME Industry 4.0 engagement

The ongoing collaboration between the Australian Industrial Transformation Institute (AITI) and BAE Systems Australia – Maritime (BAESAM), with support from the Innovative Manufacturing Cooperative Research Centre (IMCRC), has provided a broad range of industry stakeholders with the opportunity to trial and experience Industry 4.0 enabling technologies, encouraging connections, building industry and research networks and contributing to an Industry 4.0 ecosystem where knowledge is fluid and iterative, shaped by each interaction of communicator and receiver. Central to the ecosystem is the notion of market pull and technology push, with universities exploring the challenges and opportunities facing enterprises in either state and serving as a conduit for bridging gaps and problem solving.

AITI engaged with industry in both onsite (e.g. Pilot Factory of the Future at Line Zero, Tonsley Innovation District, research trials) and outreach activities (e.g. site visits to industry) to facilitate the adoption and diffusion of Industry 4.0 in manufacturing. This was complemented by a dissemination strategy of both traditional researcher (e.g. journal articles and conference presentations) and non-researcher output methods (e.g. industry briefs, videos). Increased future engagement and collaboration with industry through workshops and seminars and enterprise-specific projects is likely to improve industry expertise and embed Industry 4.0 technology in Australian SMEs.

The formal collaboration between AITI and BAESAM, including development of the Pilot Factory of the Future at Line Zero and work undertaken from research funding through the IMCRC, encouraged industry engagement by creating Industry 4.0 technology ‘exposure’ and ‘experience’ opportunities supporting knowledge dissemination. These opportunities boosted technology capabilities, highlighting their potential for supporting the manufacturing workforce and business objectives.

Opportunities to collaborate with SMEs more formally have been granted through State Government funding ($4 million) and investment from Flinders University ($2 million) to deliver a Manufacturing Growth Accelerator program[1] from 2023.

[1] https://news.flinders.edu.au/blog/2022/03/10/visionary-investment-in-the-factory-of-the-future-welcomed-by-flinders/

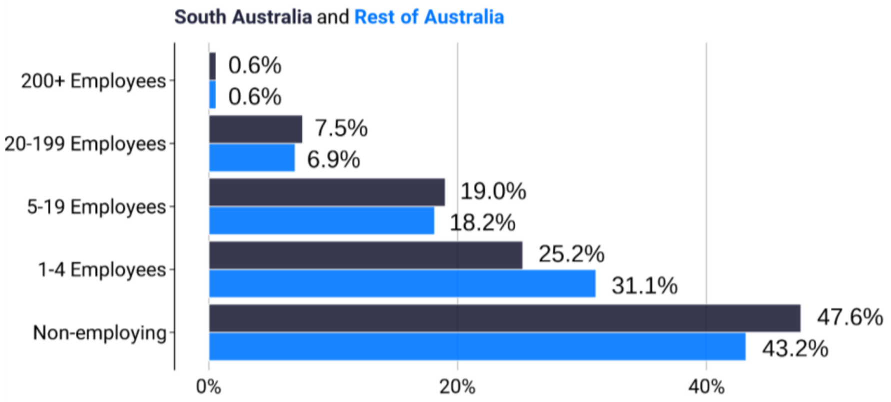
1 Industry 4.0 and the Enterprise Landscape

Both within South Australia and nationally, small (less than 20 employees) and medium-sized (less than 200 employees) enterprises (SMEs) comprise most of the employing manufacturing businesses (see Figure 1). Enterprise size is an important characteristic to consider when examining business approaches, including Industry 4.0 adoption (e.g. Rauch, Vickery, Brown, & Matt, 2020; Schroder, 2016; Worrall & Spoehr, 2021). In general, knowledge and financial resources tend to be more limited for SMEs (a condition referred to as resource poverty) which can increase the risk and reservations associated with change (e.g. Kumar, Khurshid, & Waddell, 2014; Spoehr et al., 2020; Welsh & White, 1981).

A small business is not a little big business

(Welsh & White, 1981)

Figure 1: Manufacturing businesses by employment size at June 30, 2021



Source: Australian Bureau of Statistics (2021)

Garengo, Biazzo, and Bititci (2005, p.26) summarise key parameters which differ by enterprise size:

> *Small and large firms are fundamentally different from each other in three central aspects: uncertainty, innovation and evolution…the central distinction between large and small firms is the greater external uncertainty of the environment in which the small firm operates, together with the greater internal consistency of its motivations and actions.*

For example, in terms of external uncertainty, changes in government regulations, tax laws, labour and interest rates influence a greater proportion of SME expenses compared to larger companies (Welsh & White, 1981). Differences more specific to Industry 4.0 adoption are discussed below.

1.1 Industry 4.0 Maturity and Readiness

Mittal, Ahmad Khan, Romero, and Wuest (2018) and Worrall and Spoehr (2021) are among those providing a summary of Industry 4.0 maturity models, frameworks and readiness assessments. These tools tend to capture the extent of an enterprise's capability, on a range of dimensions, to action and productively utilise digital technologies (Worrall & Spoehr, 2021). Mittal et al. (2018) emphasised the need for inclusion of 'level 0' (absence/incomplete/novice) in such models to more accurately reflect the starting point of many SMEs. Moreover, they recognised the evolution from 'level 0' to 'level 1' (existence/performed/advanced beginner) is much steeper than transitions between other levels or stages and requires a concerted shift in individual mindset and organisation culture (also see Howard, O'Keeffe, Hordacre, & Spoehr, 2022). Mittal et al. (2018, p.211) explain that for an SME,

> *A transition from manually maintained records to digital records, be it a proprietary database or a sophisticated ERP/MES solution, requires more resources and significant efforts. However, changing from existing digital records to, e.g., mobile applications may be comparatively easier.*

SME readiness for or maturity level of Industry 4.0 adoption tends to be relatively low, on average, both internationally and within Australia (Mason, Ayre, & Burns, 2022; Mittal et al., 2018; Worrall & Spoehr, 2021). In the survey by Stentoft, Wickstrom, Philipsen, and Haug (2021) of 190 Danish manufacturing enterprises with between 10 and 250 employees, uptake was found to be greatest for cybersecurity, cloud computing and mobile technologies (although ratings ranged from 2.66 to 2.35 on a scale where 1= applied to a very low degree and 5= to a very high degree) with very limited applications of augmented reality (average=1.14), artificial intelligence (average=1.22) and Radio Frequency Identification/Real-Time Location System (average=1.28). The survey identified overall cost reduction and improved time-to-market as the strongest drivers for SMEs to utilise Industry 4.0 technologies. However, a lack of human resources and high operational focus (rather than on development) were shown to be among the greatest barriers (although all average ratings were 3.0 or below – i.e. not particularly strong drivers and barriers (Stentoft et al., 2021)).

Horvath and Szabo (2019) compared the driving forces and barriers of Industry 4.0 adoption across a range of SMEs and multinational companies (MNEs) within the Hungarian ecosystem, including businesses acting as technology suppliers, users and both supplier and user (total number of companies = 26). Greatest relative discrepancies in driving and restraining forces are summarised in Table 1 and Table 2, respectively. Orzes, Poklemba, and Towner (2020) examined barriers for manufacturing SMEs to Industry 4.0 implementation through focus groups with senior managers across four countries (Italy, Austria, Thailand and USA). Their qualitative analysis (summarised in Table 3) yielded similar themes to other studies discussed here.

Table 1: Key differences in Industry 4.0 facilitators between SMEs and MNEs

SMEs	Driving Force (Drivers)	MNEs
HIGH	**HUMAN RESOURCES:** Need to address labour shortages; Ability to allocate employees to tasks that generate higher added value	LOW *(Locally HIGH)*
LOW	**MARKET CONDITIONS AND COMPETITORS:** Remain in market/increase market share through innovation; allow development of new business models	HIGH
LOW	**MANAGEMENT EXPECTATIONS:** Increase control via digital technologies – continuous real-time performance measurement, including for employee performance appraisals	HIGH

Small and medium-sized enterprises (SMEs); multinationals (MNEs)
Source: Based on results of Horvath and Szabo (2019)

Table 2: Key differences in Industry 4.0 barriers between SMEs and MNEs

SMEs	Restraining Force (Barriers)	MNEs
HIGH	**FINANCIAL RESOURCES AND PROFITABILITY:** Requires access to capital to invest in new technologies; focus on return on investment	LOW
LOW	**ORGANISATIONAL FACTORS:** Requires flexible structure and processes to support the fast flow of information and meeting of necessary requirements; lack of understanding, fear of unknown and competing/contradictory interests across business may occur, resulting in resistance	HIGH
LOW	**TECHNOLOGY AND PROCESS INTEGRATION, COOPERATION:** Requires development of a unified communication protocol across supply chain; secure data storage and business intelligence systems for analysing big data generated; development of technology standards and process standardisation	HIGH

Small and medium-sized enterprises (SMEs); multinationals (MNEs)
Source: Based on results of Horvath and Szabo (2019)

Table 3: Organisational barriers for manufacturing SMEs to Industry 4.0 implementation

Theme	Description
Economic/financial	High investment required, lack of monetary resources, lack of clearly defined economic benefit, product characteristics (low value product not worth investment)
Cultural	Lack of trust between partners, lack of support by top management, preferred autonomy (lack of sharing between companies), restrictive mindset (unwillingness to take risks), unsupportive organisational structure (e.g. decision making), low acceptance of employees, lack of support from customer/supplier, focus on day-to-day operations, limited awareness of the potential of specific technologies, low IT support
Competencies/resources	Lack of skilled employees/lack of technical knowledge, complexity of knowledge required, high coordination effort with suppliers, factory layout constraints
Legal	Data security concerns, lack of support from government, bureaucracy, restrictive laws and regulations
Technical	Uncertainty of system reliability, weak IT infrastructure, difficult interoperability/compatibility
Implementation process	Lack of methodological approach, required time and changes, difficulties in demand forecasting, product characteristics (flexibility is highest priority)

Small and medium-sized enterprises (SMEs)
Source: Reproduced from Orzes et al. (2020)

From an Australian perspective, a recent qualitative study (semi-structured interviews) of 20 Australian manufacturing companies (13 of which had more than 200 employees) showed that robotics, modernised software, sensors and additive manufacturing were most front of mind in terms of Industry 4.0 adoption and data security among the least (Mason et al., 2022). Specifically in relation to SMEs, a case study examination of 11 South Australian enterprises (ranging in size from micro (fewer than 5 employees) to large (200 or more employees)) found that small firms struggle the most with Industry 4.0 transformation largely due to lack of skills (especially non-technical skills such as workforce readiness for change) and insufficient digital capability to manage data for internal and external operations (Xing, Cropley, Oppert, & Singh, 2021).

Following these findings, Xing et al. (2021) recommended that for enterprises to increase their Industry 4.0 maturity they need to engage in external collaborations and participate in Industry 4.0 skills and knowledge education and research. In a similar vein, Halse and Ullern (2017, p.247) articulated in their evaluation of eight Norwegian SME manufacturing business case studies,

> *We see that organisations that have progressed furthest in implementing Industry 4.0 related concepts are the ones that make active use of their external network in cooperation and sharing knowledge.*

2 Industry Engagement with Universities

Engagement refers to the process of encouraging people to be interested in the work of an organisation[2], in this case enticing SMEs to be interested in, and see the benefits of working with universities. At its simplest level, engagement is conceptualised as “stakeholder dialogue” that focuses on activities intended to create opportunities for communication between an organisation and its stakeholders with the aim of informing organisational decisions (Jonas, Boha, Sörhammar, & Moeslein, 2018 p. 401). Willingness to engage depends on the motivating force – a product of the interaction between readiness, confidence in the process, and the perceived importance of the potential outcomes (Braithwaite, 2011), as depicted in Figure 2. Readiness is influenced by perceptions of the need for change in the business, and the ability to overcome ambivalence and make new ideas work in practice. Importance refers to the potential impact of making change including risks and opportunities, while confidence encompasses self-efficacy in making prudent decisions and having capability to successfully implement them (Braithwaite, 2011).

Figure 2: Three key dimensions of engagement motivation

Source: Reproduced from Braithwaite (2011 p. 498)

2.1 Factors facilitating engagement

Engagement encompasses behavioural, cognitive and emotional dimensions that explain why and how stakeholders contribute resources to inter-organisational services (Jonas et al., 2018). In the context of Industry 4.0 technology adoption, engagement relates to interactions, service exchanges, participation in co-creation processes or solution development to address immediate or future industry needs (Loureiro, Romero, & Bilro, 2020). Stakeholders interact and build on shared interests, with the intention of forming a co-operative and strategic position that will be mutually beneficial (Loureiro et al., 2020).

Successful engagement with industry is built on individual and organisational antecedents. Individual factors include leadership styles, empowerment, and compatible attitudes and goals exemplified through sharing common experiences, building trust and being able to represent the business. Organisational factors including culture, capabilities and resource dependencies, compatible institutional arrangements, technology platforms and physical proximity are other highly influential factors in cultivating industry engagement (Loureiro et al., 2020).

[2] Definition of engagement, accessed from https://dictionary.cambridge.org/dictionary/english/engagement

Viewing industry as a stakeholder of universities, engagement is increasingly being conceptualised as occurring within and between ecosystems, where interactions aimed at integrating resources are connected by shared institutional arrangements and mutual value creation (Jonas et al., 2018). In innovation, collaboration is a more formalised process than engagement, and provides a more extensive resource base to draw on[3]. Consequently, as engagement deepens, each stakeholder grows more dependent on others' knowledge and resources, becoming more reliant on each other, forging stronger relationships over time.

For SMEs, relationships with a variety of stakeholders are essential for value creation, providing knowledge, social and human capital that can enhance innovation success. Engagement with universities can provide formal education, access to a range of disciplinary perspectives (e.g., business and technology), and social connection to scientific networks allowing integration into scientific communities (Leonidou, Christofi, Vrontis, & Thrassou, 2020). Such networks can open opportunities for broader connections with technology suppliers who provide valuable sources of practical skill and experience in the early stages of adoption. These connections help SMEs focus on fundamental internal resource and customer needs early in the innovation journey. SME willingness to engage beyond their organisation is highly influenced by their lack of engagement experience and the perceived benefits that establishing technology resources will convey for their businesses. University engagement is often sought to help accelerate and expand such capability (Lai, 2011).

The level to which businesses continue to engage with universities has been conceptualised in terms of six determinants that drive decision making and were initially described by Oliver (1990) (cited in Ankrah, Burgess, Grimshaw, & Shaw, 2013 p. 58). *Necessity* refers to the requirement to meet regulations and legislation, while *asymmetry* describes the extent to which an organisation attempts to exert control over another entity or its resources. In contrast to asymmetry, *reciprocity* refers to co-operation and collaboration between organisations. A focus on *efficiency* highlights an internal priority for strategic use of resources, while *stability* seeks to minimise environmental uncertainties to better predict the future. Finally, *legitimacy* refers to conforming with the norms, assumptions or expectations that others may have of the engagement. According to Ankrah and colleagues (2013), the main determinants influencing industry to engage with universities are summarised in Table 4.

Table 4: Industry drivers for engaging with universities mapped to engagement determinants

Determinant	Industry drivers for university engagement
Necessity	Meeting government and legislative policy
	Developing and implementing strategic institutional policies
Reciprocity	Ability to attract collaborative funding for projects
	Access to students for internship or hiring
Efficiency	Commercialising with the university for financial benefit
	Cost savings
	Enhancing technological capacity and improving competitiveness
Stability	Business growth
	Access to new knowledge
	State of the art research knowledge and facilities
	Solutions to specific problems
	Relationships with academic partners who are a good fit to meet business needs

Adapted from Ankrah et al. (2013 p. 59)

Industry stakeholders have reported multiple benefits from engaging with universities that can be classified in three broad areas: financial and economic, benefits to the organisation, and benefits to society. Conversely, engagement may also have its disadvantages in terms of deviating from

[3] For further discussion on University-Industry Collaboration see Spoehr et al. (2022).

organisational mission, quality issues, and conflicts and risks (Ankrah et al., 2013). The potential benefits and disadvantages of industry engagement with universities are summarised in Table 5 and Table 6, respectively.

Table 5: Reported benefits for industry of university engagement

Category	Benefits of engagement experienced by industry
Economic	More cost-effective than similar research in-house
	Potential for public grants & funding
	Improved products and processes
Institutional	Improved innovation ability & research base
	Exposure & access to new knowledge and leading-edge technologies
	Keep current with technology developments & university research capabilities
	Solve specific problems or tailored projects
	Opportunity to access wider network of research expertise
Social	Enhanced reputation and credibility in industry community
	Stimulating and fulfilling

Source: Adapted from Ankrah et al. (2013 p. 60)

Table 6: Reported disadvantages to industry of engagement with universities

Category	Disadvantages of engagement experienced by industry
Deviating from organisational mission	Raises high expectations
	Perceived unethical practices
Risks	Reduced control or leakage of commercial information, favouring competitors to innovate faster
	Risk of incomplete transfer or under-performance of technology
	Uncertainty of commercial success of products

Source: Adapted from Ankrah et al. (2013 p. 60)

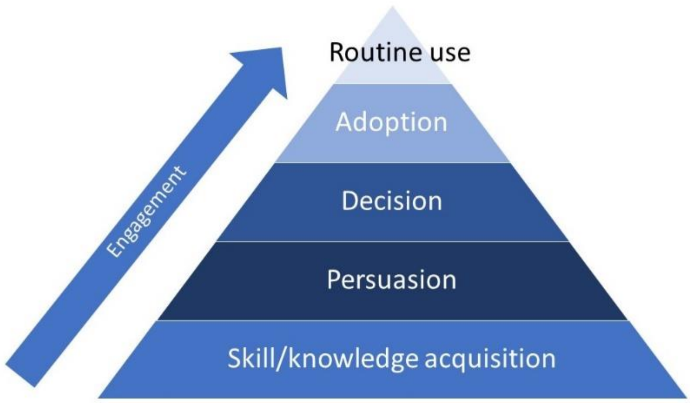
Overall, in terms of drivers, industry stakeholders ranked stability as the most important factor in driving engagement with universities, followed by efficiency, necessity and reciprocity. For outcomes, industry rated institutional benefits most highly, followed by economic gains. Deviation from organisational mission was ranked the most important disadvantage from engagement, followed by risks.

3 Developing an Industry 4.0 Ecosystem

Drivers of innovation can have their origins in market pull, where customer needs are not being adequately met, creating a demand; or through technology push where new products and processes are initiated from research aimed at capitalising the application of new knowledge (Brem & Voigt, 2009). Market pull results in growing demands from end users to problem-solve the gaps in existing solutions, while technology push arises from harnessing the potential in a technical capability. Technology push therefore has greater capacity to initiate radical innovation, where more incremental innovations and improvements are achieved through market pull.

Engagement with technology begins through stimulating curiosity about the possibilities for realising goals faster, easier or in more cost-effective and satisfying ways. Raising awareness of new opportunities is the first step in engaging prospective users to seek new information and acquire knowledge about the benefits of technology uptake. This process of discovery encourages exploration, experimentation, and skill development, ultimately persuading a decision to (reject or) adopt technology if there is readiness to invest and implement. Successful adoption efforts culminate with routine use of technology (see Figure 3) and changes to work practices and business models (Benson, 2019). Engagement increases as potential adopters move through the progressive stages of familiarising with technology, until reaching a level of capability to sustain business performance. These stages are consistent with the innovation-decision process for individuals from Rogers' diffusion of innovation theory (Sahin, 2006): knowledge (includes awareness knowledge, how-to knowledge and principles knowledge, has a more cognitive focus), persuasion (formation of attitude, focuses more on emotions), decision (reject or adopt), implementation (uncertainty of consequences/outcomes may be present, reinvention[4] can occur) and confirmation (seek reinforcement of decision, continued adoption or discontinuance).

Figure 3: Stages of engagement in technology adoption



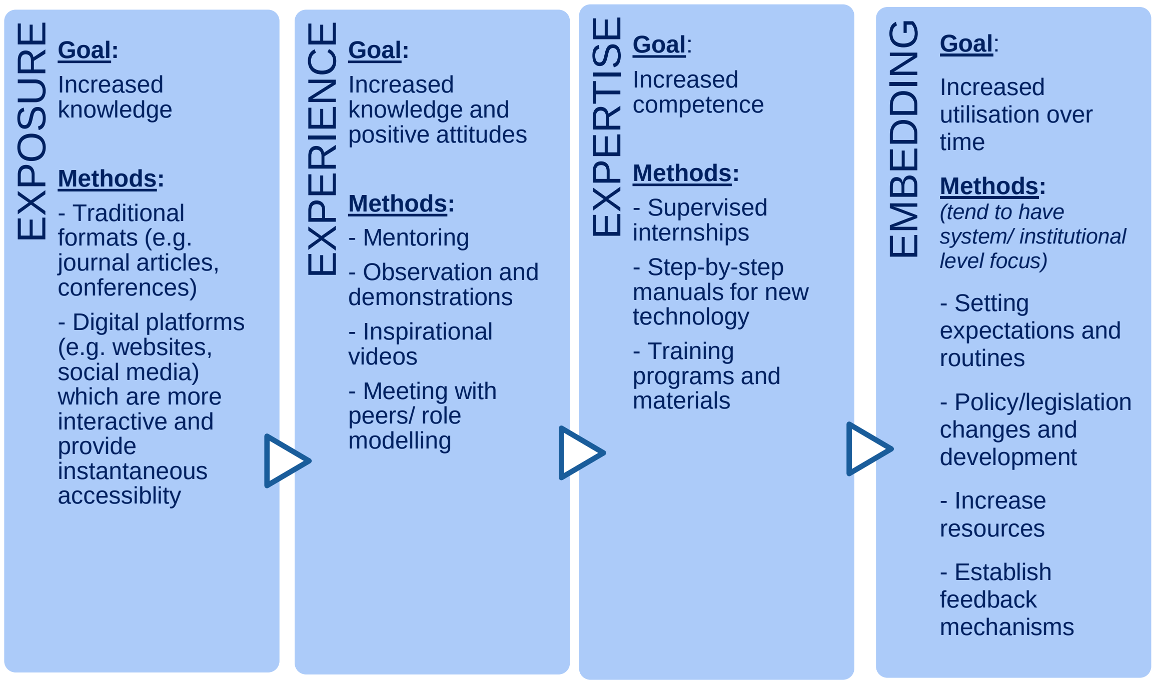
Source: Adapted from Benson (2019)

According to Rogers (1983 cited in Farkas et al. (2003)), knowledge dissemination is a relatively simple process of communicating new findings and outcomes to others and is one part (knowledge stage) of the diffusion process (Bauman, Nelson, Pratt, Matsudo, & Schoeppe, 2006). Dissemination is considered a critical element in the research to practice (knowledge

[4] Users modify the innovation, it is no longer a 'new idea'. The greater the reinvention, the more rapidly the innovation is adopted.

translation) continuum (Wilson et al., 2010). Farkas et al. (2003, p.48) emphasise the distinction between knowledge dissemination and knowledge *utilisation* – the latter being *'a more complex process of applying the knowledge that is disseminated'*. They demonstrate a '4E' framework that provides four dissemination and utilisation strategies based on unique goals and specific translation methods that are to be selected according to the likely target group/stakeholders involved (see Figure 4Table 4 for an overview).

Figure 4: A framework for promoting dissemination and utilisation of research/evidence/innovation



Source: Adapted from Farkas et al. (2003)

Thus, effective dissemination of information needs to be planned and requires a clear understanding of the communicator (e.g. researchers) and users (e.g. industry, policymakers) such that messages are tailored to different audiences (Farkas et al., 2003). Brownson, Eyler, Harris, Moore, and Tabak (2018) reviewed different approaches and tools for dissemination to non-research audiences within a public health context. They concluded that *'practitioners and policy makers can be more effectively reached via news media, social media, issue or policy briefs, one-on-one meetings, and workshops and seminars'* (Brownson et al., 2018, p.102). Moreover, to enhance knowledge translation, researchers should design for dissemination at the outset where stakeholders are actively involved in the information/innovation generation opportunity, increasing the likelihood that outcomes will address 'adopters' needs (Brownson, Jacobs, Tabak, & Hoehner, 2013).

One of the most effective ways to stimulate interest and provide opportunities for discovery is through direct hands-on, practical experience. In fact, *'Rogers claimed that the likelihood of adopting an innovation increases if there are opportunities for hands-on experience with it'* (Frei-Landau, Muchnik-Rozanov, & Avidov-Ungar, 2022, p.14). An Israeli study exploring the mobile learning application[5] experiences of 32 teachers (pre-service and in-service, specialising in

[5] For example, virtual whiteboards, online quizzes, interactive presentations and preparation of videos.

kindergarten to high school education) endorsed this association (i.e. hands-on experience *'significantly advanced the decision to adopt the technology'*, (Frei-Landau et al., 2022, p.14)) and affirmed the importance of trialling technology in an environment where technical expertise is in close proximity and support is provided as needed. In his review of Rogers' diffusion of Innovation theory, Sahin (2006, p.3) described that a *'vicarious trial can speed up the innovation-decision process'*.

Mechanisms for industry engagement, collaboration and knowledge transfer with external stakeholders/universities can be formal (e.g. contract agreements, venture investment, technology licensing, patent purchase) or informal (e.g. trade fairs, conferences, seminars/workshops, sharing facilities). In the context of Australian universities, formal channels typically include research centres, incubators, contract-based research and commercialisation. Informal channels include industry mentoring/internships for university students, industry talks and projects, and industry access to university facilities such as Living Labs[6], (Dang, Jasovska, & Rammal, 2019). A survey of 213 high-tech manufacturing SMEs in China found that whilst both types of interaction (formal and informal) enhanced the innovation performance of businesses, informal external collaboration was most beneficial (Lu & Yu, 2020).

[6] Living labs and teaching factories (Mourtzis, Vlachou, Dimitrakopoulos, & Zogopoulos, 2018) are dynamic, unrestricted spaces that allow for co-creation of ideas and solutions which can be tested; also see Spoehr et al. (2022).

4 A model of Industry Engagement & Dissemination

The formal collaboration between the Australian Industrial Transformation Institute (AITI) and BAE Systems Australia – Maritime (BAESAM; detailed in Spoehr et al. (2022)), has resulted in numerous industry engagement and dissemination opportunities which align with two broad approaches:

- On-site activities, including inviting industry participants to observe a demonstration or have 'hands-on' experience with using technology; and
- Outreach activities, including working with technology providers and seekers to link solutions and problems.

The principal mechanisms for on-site engagement involved showcasing applications of Industry 4.0 enabling technologies, many derived from research trials co-funded by BAESAM and the Innovative Manufacturing Cooperative Research Centre (IMCRC), to visitors at the Pilot Factory of the Future at Line Zero, Tonsley Innovation District. The Pilot Factory of the Future is similar to the concept of living labs and teaching factories which can be considered as dynamic, unrestricted spaces that allow for co-creation of ideas and solutions which can be tested[7] (Spoehr et al., 2022). Additionally, the research trials conducted by AITI (described and summarised in O'Keeffe et al. (2022)) were an example of designing for dissemination as industry stakeholders and shipbuilding/manufacturing practitioners were consulted during the planning stage of trials as well as invited to participate in them, providing hands-on experience using technology for a real manufacturing work task.

Engagement through outreach activities mostly involved site visits to businesses who were either seeking a solution to their challenges ('problem looking for solution' or market pull), had solutions of potential interest ('solution looking for a problem' or technology push), or both. Figure 5 provides a summary of the ways in which AITI engaged with industry throughout the collaboration with BAESAM and IMCRC and is explained in subsequent sections.

4.1 On-site Activities

The fortnightly tours of Pilot Factory of the Future at Line Zero allowed the AITI research team[8] to demonstrate recent trial activity and share findings (verbal dissemination), alongside demonstrations from BAESAM and other businesses who were offering technological solutions to advance manufacturing and heavy industry (e.g. wireless communication/RFID, low voltage lighting with in-built sensors for monitoring). These businesses had often been involved in BAESAM's Innovation Challenges[9]. The interactive format of the tours allowed for questions and follow-up connections to be made – including between visitors, between demonstrators and between visitors and demonstrators. On-site activities are represented by the horizontal dashed arrow in Figure 5.

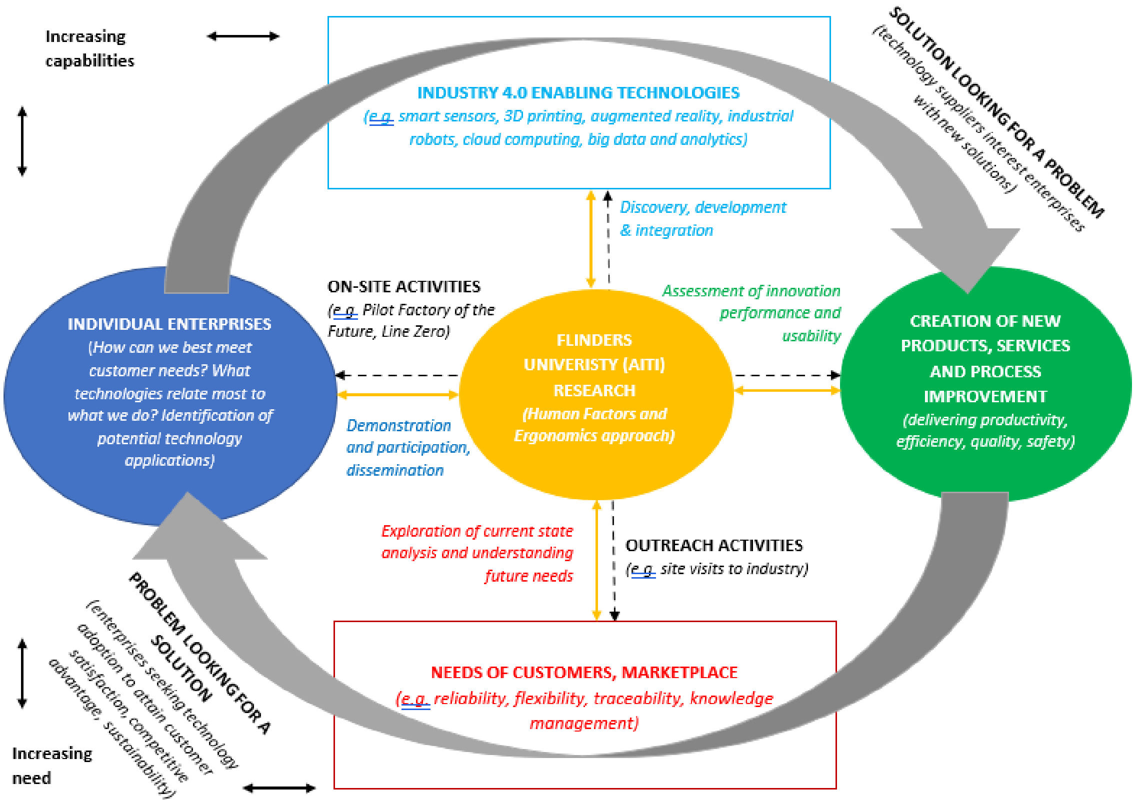
More than 2,000 visitors have attended these tours since March 2020 comprising a range of sectors including manufacturing, defence, government and education. We expect a relatively large snowball effect from these tours, where attendees share their experience and knowledge with colleagues, family, and friends, promoting future engagement with the AITI-BAESAM collaboration, Industry 4.0 and human factors and ergonomics. Exposure to education providers

[7] https://livinglabs.lakeheadu.ca/living-lab-approach/
[8] Comprising social scientists (including psychology, human factors and ergonomics) and engineers (mechanical, robotics and biomedical)
[9] https://www.baesystems.com/en-aus/article/inaugural-winners---innovation-to-underpin-hunter-frigates-

and students and apprentices is particularly valuable in order to promote careers in STEM and illustrate current and future competency requirements (see the skills and job design report by Howard et al. (2022) for further discussion on this topic).

A tour of Pilot Factory of the Future was also incorporated into the two futuremap workshops[10] hosted by AITI and facilitated by the IMCRC. Futuremap is an Industry 4.0 maturity assessment tool[11] (also see Worrall and Spoehr (2021)) with the workshops seeking to increase awareness and knowledge about Industry 4.0 as well as to inspire action and increase engagement in Industry 4.0 enabling technologies and the benefits they can bring business. Approximately 30 senior leaders representing 19 different enterprises attended in total with many 'ah-ha' moments created, particularly for enterprises at lower levels of digital maturity. For example, a national engineering solution business was enthusiastic about bringing the rest of their team for a tour, recognising the potential for technologies such as augmented reality to enhance their processes.

Figure 5: An engagement and dissemination framework for accelerating the adoption and diffusion of Industry 4.0 in manufacturing



Source: Adapted from Rothwell's (1995) Third Generation Coupling Model of Innovation (cited in du Preez and Louw (2008))

Over the two and a half-year project, five AITI-led research trials have been conducted involving a total of 81 participants. Approximately one-third of these participants were from local industry, with the remainder comprising employees from BAESAM (e.g. the research and technology unit at Tonsley, production staff from Osborne shipyard). Results from the trials and other associated research collateral are publicly available on the AITI website[12]. AITI outputs particularly targeted

[10]Delivered on 5 August 2021 and 24 May 2022
[11] https://futuremap.org.au/
[12] https://www.flinders.edu.au/australian-industrial-transformation-institute/human-factors-in-advanced-manufacturing

to industry are the videos and implementation guides, with industry briefs (summary reports) accompanying most longer reports. When outputs are made available, they are further disseminated on AITI's social media pages (e.g. LinkedIn), spearheaded by AITI Director, Professor John Spoehr who is well-networked and respected among government and industry leaders. More traditional forms of research dissemination (i.e. journal articles and conference presentations) have also occurred and are provided in Appendix A.

AITI complemented the research trial engagement with BAESAM with other forms of research by conducting a digital workflow readiness survey of personnel at both Osborne and Henderson shipyards. The survey assessed attitudes towards digital workflow systems (perceived benefits and concerns) as well as perceptions of the current job and work environment, including perceived challenges to completing work. Data analysis and feedback to the business allowed the identification of strengths and development areas to inform change management strategies and formulate recommendations to prioritise actions.

Both the research trials and tours of Pilot Factory of the Future at Line Zero enabled a range of industry and other stakeholders to engage in knowledge transfer and share in how AITI solved both technical and implementation (e.g. safety) challenges of Industry 4.0 enabling technologies and related tasks. A concrete example of this was AITI developing a 3D-printed part to prevent an electrical cabinet from accidentally closing. Visitors to Pilot Factory of the Future endorsed this solution and subsequently made enquiries regarding design, and time and cost of manufacturing.

4.2 Outreach Activities

Outreach activities are represented by the vertical dashed arrow in Figure 5 and examples are provided below, grouped in terms of market pull and technology push.

Market pull – a problem looking for a solution

To ensure the research undertaken by AITI was complementary and relevant to BAESAM and the broader manufacturing supply chain, AITI sought out and accepted invitations to understand the current state of businesses – that is, their current needs and pain points. With respect to BAESAM, this entailed visits to Osborne shipyard and consultation with various subject matter experts including: Safety, Health and Environment (SHE) advisors about safety management including emergency response and environmental monitoring and working in confined spaces; and supervisors from blasting and painting, piping fabrication, and dimensional inspection. These conversations reflected a desire to reduce or eliminate safety and wellbeing hazards for personnel as well as increase the precision and quality of work (reducing rework, waste and bottlenecks).

The AITI-led research trials culminated in the fifth and final trial activity (electrical cabinet assembly and inspection; refer to O'Keeffe et al. (2022, p.4) for a description) being conducted at Osborne shipyard, maximising engagement across business units and roles. This engagement had two components – trial participation, largely involving shipyard production staff, and 'come and try' sessions, targeting management and administration staff (including production planning, quality assurance, training and skills, and human resources management). The 'come and try' sessions involved demonstrations (30-60 minutes) where small groups of participants could observe, try the technology and engage in discussion with researchers and fellow participants about opportunities for adoption, potential barriers and perceived business impacts. This effort provided a more in-depth experience for a range of BAESAM employees to engage with the technologies and their potential, building on a previous demonstration session held at the shipyard in December 2021.

In terms of other insights, a site visit to a medium-sized South Australian precision engineering company revealed a desire to reduce cycle times for some machining jobs with changeover between jobs being very demanding due to a lack of customisation and necessary tool cleaning and checking. In addition, all documentation and checklists used in the process are paper-based. The business was interested in exploring the use of collaborative robots for machine tending (ultimately to achieve 'lights-out manufacturing'[13]) and believed any digitisation of processes (e.g. digital work order) would be well-received by staff, provided it *'didn't make their lives harder'* (e.g. need to troubleshoot technical issues, and increased security risks associated with any mobile devices with camera functionality). The business also indicated current reluctance to shift from subtractive to additive manufacturing, due to the technology's current maturity level.

Technology push – a solution looking for a problem

BAESAM and AITI jointly attended a site visit to the research and development facility (in New South Wales) of a medium-sized enterprise who is a national market leader in surface preparation solutions to observe the application of an autonomous sand blasting robot in a confined space metal container. Production results were generally satisfactory although the robot did not detect reductions in blasting pressure from the compressor resulting in some surfaces not meeting required finish quality standards. A focus of the enterprise was how to improve the integration between the robot and compressor. A limitation of blasting robots in adequately covering every surface is an example of a deterrent for SMEs to uptake technology. For example, a medium-sized South Australian structural steel fabricator emphasised the importance of practicality and not overcomplicating a process by inserting technology, especially if a human needs to be involved to complete the work to the desired standard. This sentiment also extended to introducing welding robots where use of welding trolleys currently meets their needs. This emphasises the need for clear justification when implementing technology and applying it in ways that provide adequate return on investment.

Engagement with industry in this way helped shape the focus of the research trials in terms of specifying the nature of use cases, technologies of interest, and what evidence may be of most assistance to aid decision-making (e.g. performance outcomes, workforce attitudes). The development and execution of the research trials also required liaison with a range of suppliers, from structural equipment (e.g. pump and pipe skids, steel shipping containers, electrical enclosures) to technology specialists (e.g. inspection cameras, augmented reality software, robots). Each of these touch points contributed to raising the profile of Industry 4.0 and its potential applications in manufacturing, translating in some instances to visits to our facilities (Pilot Factory of the Future) and participation in AITI-led research trials, showcasing the value of a human factors and ergonomics approach (see O'Keeffe, Moretti, Hordacre, Howard, and Spoehr (2020) for more details).

Market pull *and* technology push

Employees from a medium-sized South Australian engineering firm (specialising in asset inspection and offering technologically sophisticated solutions) attended a tour of Pilot Factory of the Future where AITI research trial results relating to augmented reality used in a visual inspection task resonated with their work. This led to researchers visiting their business, completing a non-disclosure agreement and intentions to collaborate on future work once the business reaches its next development milestone. Staff from a large South Australian utilities provider also attended Pilot Factory of the Future seeking to discuss technical features of robotic

[13] Meaning full automation, without a person being required onsite

equipment they had recently procured and were trialling, in addition to sharing experiences of its application limitations and potential.

5 Conclusion

Stability (e.g. providing access to new knowledge and state of the art facilities, and identifying solutions to specific problems) and efficiency (e.g. enhancing technological capacity and improving competitiveness) are two key drivers for industry stakeholders to engage with universities. The formal collaboration between AITI and BAESAM, including development of the Pilot Factory of the Future at Line Zero and work undertaken from research funding through the IMCRC, encouraged industry engagement by creating Industry 4.0 technology ‘exposure’ and ‘experience’ opportunities supporting knowledge dissemination. These opportunities boosted technology capabilities, highlighting their potential for supporting the manufacturing workforce and business objectives. Providing informal, hands-on, practical experience for SMEs is a critical component in de-risking technology adoption and identifying needs for change management. Access to both technical (e.g. engineering) and non-technical (e.g. human factors and ergonomics) expertise is an especially valuable part of the de-risking process and of the AITI-BAESAM offering to industry.

However, knowledge dissemination does not equate to knowledge utilisation and increased attention and effort needs to be invested in ongoing industry engagement and support mechanisms to bolster ‘expertise’ and ‘embed’ knowledge and innovation within enterprises. To achieve this, AITI seeks to increase outreach activities to build and shape the knowledge base and importantly work together with individual enterprises so that evidence and outcomes can be tailored for their context – an important part of the human factors and ergonomics approach. This step is likely to be particularly meaningful for SMEs with low digital readiness or maturity where the degree of change will be of a more radical nature and resource support requirements greater. Broadening collaboration with industry groups (e.g. Australian Industry Group) to facilitate delivery of seminars and workshops may be a useful first step. Opportunities to collaborate with SMEs more formally have been granted through State Government funding ($4 million) and investment from Flinders University ($2 million) to deliver a Manufacturing Growth Accelerator program[14] from 2023.

[14] https://news.flinders.edu.au/blog/2022/03/10/visionary-investment-in-the-factory-of-the-future-welcomed-by-flinders/

Appendix A

The tables below list dissemination activities that are more directed to/accessible by researchers. However, the presentations were delivered at forums with reasonable practitioner attendance, adding to the expected snowballing/word-of-mouth effect from all the engagement activities.

Table 7: Summary of journal articles prepared about AITI Industry 4.0 research

Title	Target journal	Current status	Authors
Visual Inspection with Augmented Reality Head-Mounted Display: An Australian usability case study	Human Factors and Ergonomics in Manufacturing & Service Industries	Reviewed by journal, authors making revisions	Sara Howard, Ryan Jang, Valerie O'Keeffe, Kosta Manning, Robert Trott, Ann-Louise Hordacre & John Spoehr
Forming a view: A human factors case study of augmented reality collaboration in assembly	Ergonomics	Under peer review	Valerie O'Keeffe, Ryan Jang, Kosta Manning, Robert Trott, Sara Howard, Ann-Louise Hordacre & John Spoehr
Apples, Apps and Approvals: Digital Work Management in Shipbuilding	Ergonomics	Under peer review	Valerie O'Keeffe, Sara Howard, Ann-Louise Hordacre, John Spoehr

Details are correct as of 11 October, 2022.

Table 8: Summary of presentations conducted about AITI Industry 4.0 research

Title	Forum	Date	Presenter
Human factors implications of augmented reality-based work instructions in harsh manufacturing environments	14th Industrial and Organisational Psychology (IOP) Conference	7-9 July, 2022	Dr Valerie O'Keeffe (online/virtual)
Collaborative robots supporting safety and wellbeing in the blue-collar workforce: A human factors approach	14th Industrial and Organisational Psychology (IOP) Conference	7-9 July, 2022	Dr Sara Howard (online/virtual)
Setting it straight: Human factors, technology and pipe alignment in shipbuilding	Chartered Institute of Ergonomics and Human Factors (UK)	5-7 April 2022	Dr Valerie O'Keeffe (online/virtual & poster presentation)
Apples, apps & approvals: Digital work management in shipbuilding	Human Factors and Ergonomics Society of Australia National Annual Conference	8-9 November 2021	Dr Valerie O'Keeffe (online/virtual)
Can technology support human visual inspection in harsh environments?	Australian Institute of Health and Safety SALUS Conference	22 October 2021	Mr Kosta Manning (in person)
Good work design: The way of the future	Australian Institute of Health and Safety SALUS Conference	23 October 2020	Dr Valerie O'Keeffe (in-person)

Details are correct as of 11 October, 2022.

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