

# Mastery in the Digital Age

## Reconceptualizing Expertise, Developing Deep Technical Mastery, and Accelerating Effective Workplace Learning

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# Executive Summary

Our research set out to resolve a paradox.

How can human expertise ever stay ahead when it is neither transforming nor accelerating as fast as technology and workplace disruptions? How can human expertise ever catch up with the demands of the Fourth Industrial Revolution (4IR) when it risks rapidly falling behind the revolution?

Resolving this paradox means mastery can be integrated into existing upskilling and reskilling initiatives. These initiatives can become more targeted to sharpen the Singaporean workers' edge. The Singapore workforce is thus more likely to thrive, transform, and stay on top of disruption, and less likely to struggle to keep up.

Our research thus focused on how we can think about human expertise in an equally transformative sense. Our research also focused on ways to accelerate the development of mastery.

## Beyond the ladder: upgrading our understanding of mastery

We found that the approach to mastery, as it is popularly perceived today, needs an upgrade for the digital age.

The traditional understanding of mastery is that of a ladder with rungs as the levels of expertise. Individuals gradually progress up this ladder linearly as they develop their skills step-by-step from novice to expert. Workers are thus encouraged to keep upskilling towards the next higher rung, with each rung denoted as a level of expertise to be attained (Figure 1).

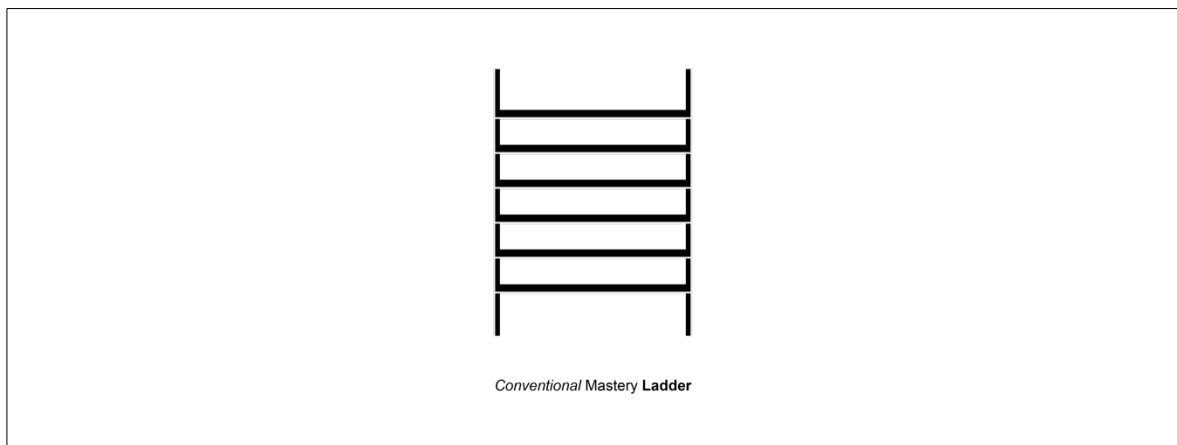


Figure 1: Conventional Mastery Ladder

This ladder model is foundational. But it is increasingly insufficient because the foundations of the ladder have shifted. A core assumption in conventional theories on expertise is that it is conceptualised as the gradual, yet rather stable step-by-step climbing of the ladder. The ladder model, together with the upskilling programs and policies based on it, fail to account for the fluidity of workplace changes and the disruption of technological advances. (Kim, 2021; Yanow, 2015)

The ladder model has in fact even fallen behind extant literature, which has pointed out there are additional dimensions, and that our understanding of mastery must also evolve alongside changes that have taken place in the work settings, skills and technology (Dall'Alba and Sandberg, 2006).

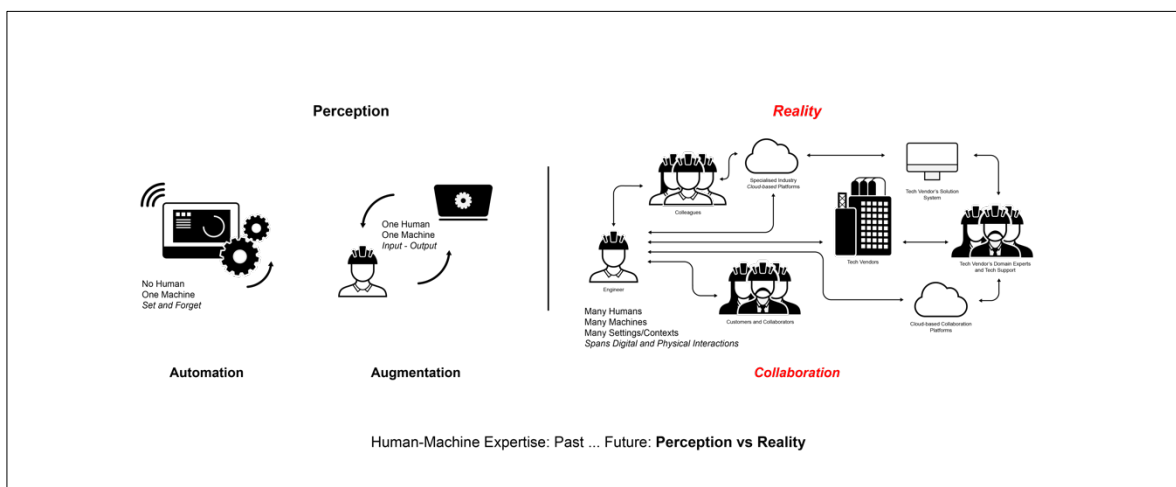
Our research confirms the ladder model is insufficient and inadequate for understanding mastery in the digital age. Moreover, our research also confirms that a new understanding must include the dimensions identified in extant literature.

### A new model of mastery: distributed and multi-faceted

Most importantly, our research uncovers a range of additional dimensions which show that mastery is now distributed and multi-faceted, reflecting the realities of the modern workplace.

Mastery and the modern workplace are distributed and multi-faceted because the expertise that needs to be marshalled to successfully innovate and operate complex systems now resides in a network of people as well as technologies. This network is spread out across disciplines, generations, organisations, and geographies.

We illustrate this with the following diagram developed from our research:



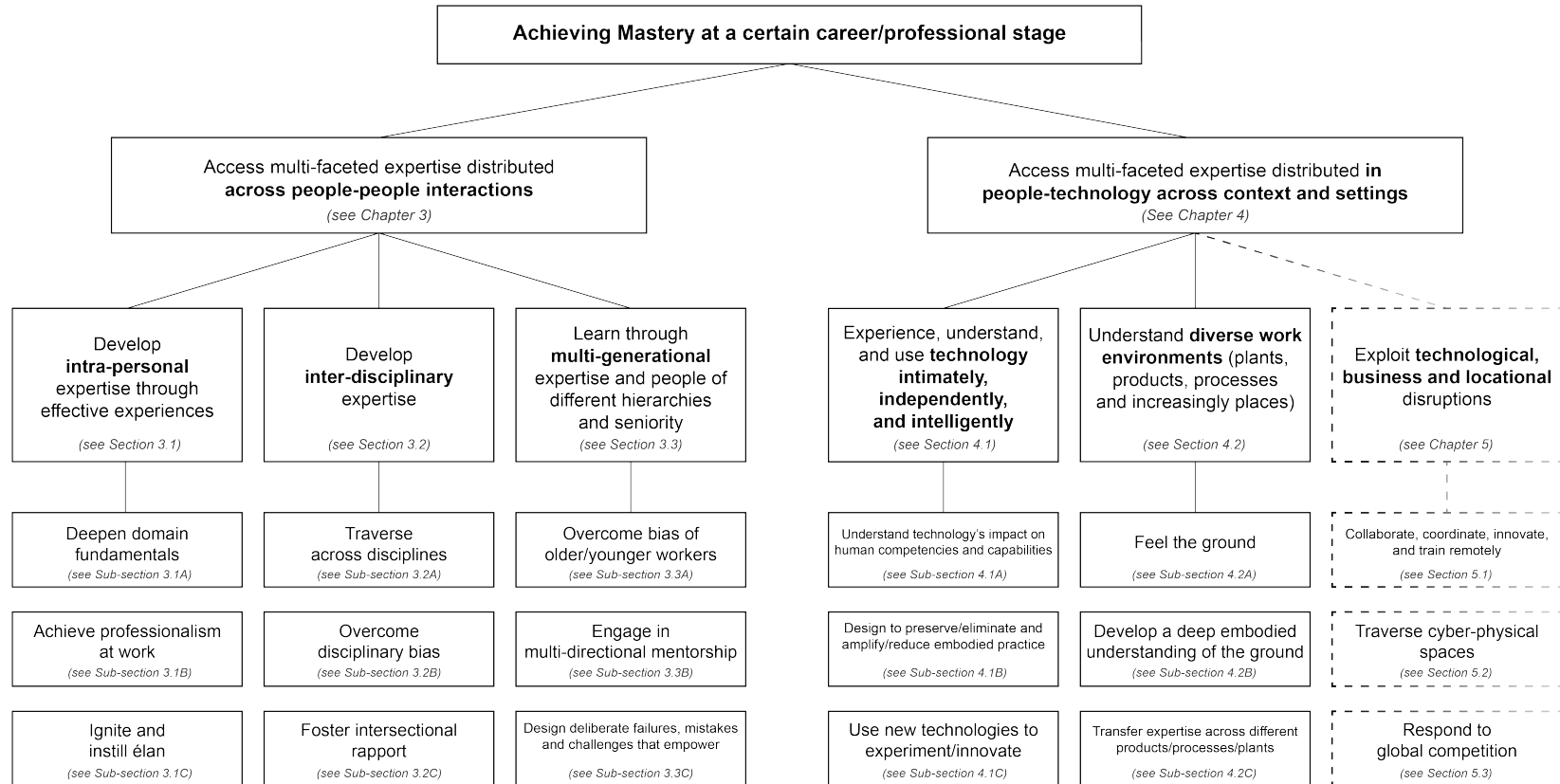
**Figure 2: Human-Machine Expertise: Past...Future: Perception versus Reality**

As the left portion of the diagram points out, there are two common perceptions of the relationship between technology and the technical professional's expertise. In automation, human expertise is replaced by technology (e.g. because it is more efficient). In augmentation, the humans and machines focus on tasks they are individually better at (e.g. humans at non-routine creativity; machines at routine tasks).

Both of these perceptions however are inaccurate and limiting. They fail to capture the realities of the modern workplace. They assume a one-to-one relationship between a human and a machine. In addition, they also assume there is a hard division of labour between humans and machines.

The reality of the modern workplace involves a many-to-many relationship between humans and machines where the division of labour is fluid. The technical professional is coordinating and collaborating across a network of people and technologies. Such a network can be several layers deep and wide. Hence, to do their jobs, technical professionals need to access the expertise that is distributed across this multi-faceted network. How well they do so reflects how deep and wide their expertise is. This distribution has been accelerated by the digital age. For example, digital communications expand this network across more geographies and people. Advances in intelligent technology and access to information have also multiplied the types of expertise and experts who can help solve a particular problem (Figure 2).

Figure 3: Multi-faceted Mastery Model (see annotations for chapters, sections, and sub-sections)



We thus need a new model of distributed and multi-faceted mastery, that also includes, integrates, and advances both the ladder model and what is already found in extant literature. Based on a qualitative study – including 250 hours of observations, 65 formal interviews and 9 focus groups – of technical professionals in Chemical and Energy (CE) and Precision Engineering (PE) industries, we have developed such a model that we call the Multi-faceted Mastery Model (Figure 3). This model is based on our extensive fieldwork and by engaging in a process of data analysis resembling grounded theory using Gioia, Corley and Hamilton's (2012) framework. This implied establishing close connections between our concrete data (presented in chapters 3-5) and the more abstract and general categories presented in our model. Based on this, chapter 6 discusses the implications of our research. It also reflects on the limitations of our findings in terms of generalising them, as well as suggesting how future research can address this in order to make our model applicable to a larger portion of the workforce.

This Multi-faceted Mastery Model integrates the ladder model and what is known from extant literature through the leftmost branch focusing on intra-personal expertise. The Model builds on them and advances our understanding of mastery with the other five branches to the right. The sixth branch is in dotted lines as it is still evolving (due to the pandemic) but is nonetheless an important lens into the nature of future mastery. In addition, all six branches are categorised according to whether they are about people-people interactions or people-technology interactions. These two categories account for what we explained earlier, that expertise is now distributed across a multiplicity of people and technologies.

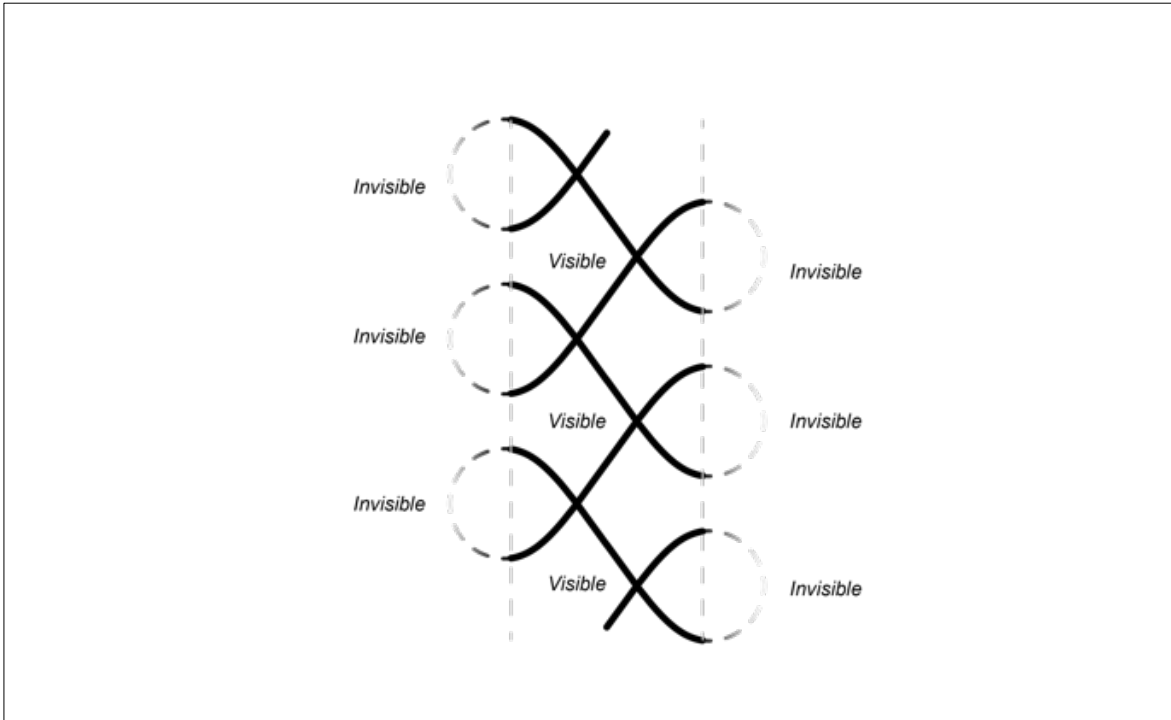
#### **Designing Multi-faceted Mastery Model: libraries and loops and making the invisible visible**

The immediate implication of the Multi-faceted Mastery Model is that we also need to update our conceptualisation of mastery. Without an accurate conceptualisation, we are less likely to diagnose why and what is wrong. Any subsequent interventions will be ineffective. An accurate one on the other hand, makes it more likely we will diagnose and design the right interventions.

If the conventional model, with its conceptualisation of mastery as a ladder is outdated, it is equally important to replace it with an accurate conceptualisation of mastery where the role of technology and digital tools vis-à-vis human workers at the workplace is actually more nuanced.

We propose the library as the replacement. Given the contemporary workplace is a network with many humans, many machines, and many settings spanning across digital and physical spaces through feedback loops and interactions, mastery in the digital age is more like a library, with its multi-faceted and distributed collections across many floors. To access them, one needs to traverse across them, sometimes progressing upwards, sometimes progressing sideways, and sometimes progressing downwards before one can go upwards or sideways.

In addition, it is also outdated to simply think of the levels of expertise as steps to be taken. It is more useful to think of them as invisible-visible loops. Such loops are useful because both the network of people and technology, and technology itself can make the nature of expertise increasingly invisible. The invisible-visible loops thus help us see where expertise is or has become invisible. We can then design the interventions to pull what is invisible into the visible, and subsequently into a reinforcing series of loops that build up mastery. We explain these below (Figure 4).



**Figure 4: Multi-faceted Mastery Loops**

First, the network. When mastery is multi-faceted and distributed across people and technologies, at any point in time, a technical professional will only have sight of some of the expertise in the network. The rest of the expertise needed from other people and technologies will be invisible unless he or she has a way to access them. For example, take the ground expertise that an experienced technician has, and the digital expertise that a “digital native” young technician has. Their respective expertise are visible to themselves but invisible to each other. For each of them, their ability to start from what is visible, and to traverse to and pull in the invisible determines if they have all the expertise needed to run the operations and to solve problems.

Traversing this loop is harder than it sounds. This is because they each have to find a way to articulate what is visible to themselves but invisible to others in ways that are accessible to others. This is neither trivial nor straightforward because of differences in disciplines, generations, seniorities, technology affinities etc. (see the second to sixth branches of the Multi-faceted Mastery Model diagram in Figure 3).

Traversing the visible-invisible loop becomes more challenging when one multiplies it with the number of invisible expertise that one has to access (Figure 5). In addition, each time one loop is successfully traversed, a new loop will present itself when the technical professional has to solve a more complicated or complex problem, or when a new challenge crops up. That said, successfully traversing these multiple loops is how a technical professional builds up mastery in the digital age, which we will show throughout this report.

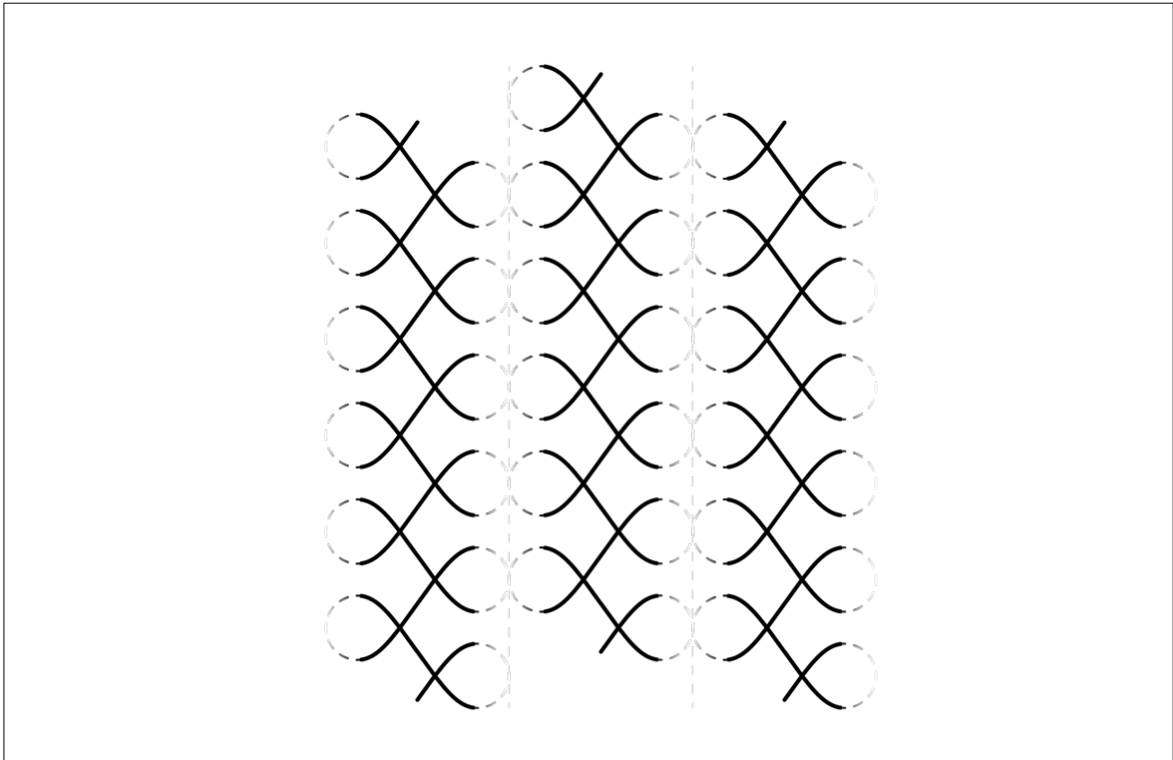


Figure 5: Library of Mastery Loops

Second, technology itself. In addition to modern workplace mastery being distributed between a wide range of actors and technologies, technology itself also obscures how and what type of expertise really matters. For instance, while automated systems have made flying safer than ever before, it has also reduced the pilot's ability to fly a plane manually (Carr, 2014). In the wrong situation, this can lead to catastrophic results.

How did this paradox come about? In popular discourse, the automation of human expertise has been described as something of societal benefit: predictable machines will replace unpredictable human action (Susskind & Susskind, 2016). Yet, this view assumes that what humans and what machines can do is more or less similar so that one can replace the other. This view, however, fails to capture the essence of expertise as seen from our auto-pilot versus pilot example. In the diagram above, it means that what is visible and invisible can shift with the adoption of new technologies, and what has become visible or invisible is not always immediately apparent.

Throughout our report we will refer to this as mastery becoming invisible, and we also show how the risks of this phenomenon can only grow with the increasing use of technology, and what we can do in response.

It is important to point out that the invisible-visible phenomena also explain why there is a big gap between how digitalisation is perceived and how it is actually operationalised in the engineering industry.

The expectation of a highly digitalized workplace with widespread use of automation and augmentation technologies vis-à-vis human workers does not align with the current realities of a *multi-faceted workplace* where in actuality, the ratio of human workers to digital and non-digital technologies is less skewed than what is being portrayed. The proponents of the highly digitalised workplace have failed to see where expertise really lies because technology has obscured their view.

## About our Research

The Multi-faceted Mastery Model and our proposed new approaches to designing mastery were developed from our research project. This research project sets out to explore the meaning of mastery for technical professionals when jobs and workplaces are increasingly being digitalised. The chief premise of our research is that the very core of what it means to be good at one's job is challenged and may fundamentally change when parts of that job are taken over, e.g. by robots automating manual tasks or Artificial Intelligence (AI) taking over cognitive tasks. In the 4IR, change has been happening at an increasingly faster pace. Tasks, jobs, occupations and even entire professions are subjected to continual transformation. However, mastery has long been understood as the step-by-step, incremental development of skills over a long period of time in individuals' careers as they gradually progress from novice to expert. Therefore, this poses a paradox and suggests the need to re-evaluate the meaning of mastery given the implications it has on Singapore's policies involving workforce development.

This study was funded by the Institute for Adult Learning to gain a better understanding of how we can obtain mastery at certain levels of our career or professional stage. In this report we draw on ethnographic data collected between September 2019 and April 2021. We focused on technical professionals working in the Chemicals and Energy (CE) and the Precision Engineering (PE) sectors. In total, we conducted 65 interviews, 9 focus groups, as well as 250 hours of observations at a Chemical Engineering pilot plant within one of Singapore's polytechnics and at two companies in the Precision Engineering sector.

What the technological professionals told us was illuminating. Equally illuminating was what they did in their work but did not tell us, which we were able to uncover through our observations, and which gave us an in-depth glimpse into two industries that are generally not studied ethnographically. This combination of what they did, did not tell us, and did tell us – and their integration into a holistic view – informed our findings. Those findings – detailed in chapters 3, 4, and 5 – are at the core of the Multi-faceted Mastery Model, and our recommendations (chapter 6).

## Recommendations

Our observations and interviews yielded novel and grounded research insights that lent themselves readily to seven actionable recommendations.

**1) Design a Multi-faceted Mastery Model to guide the development of deep, distributed, and multi-faceted expertise in the digital age.** This model, which we introduced earlier in this Executive Summary (see Figure 3), updates the ladder model of expertise to reflect the modern multi-faceted and distributed workplace where there are networks of many-to-many human and technology relationships. An updated model means we can design better and more targeted interventions.

**2) Design targeted interventions (initiatives, incentives, and guidelines) for different dimensions of mastery.** We adapted the practical strategies that our research participants used to develop mastery into specific interventions that professionals, companies, Institutes for Higher Learning, and government agencies can use to target different dimensions of mastery.

**3) Track professionals' progress of mastery over time and at seminal stages of their careers.** We show how existing approaches can be used to survey professionals to assess the effectiveness of different interventions, and to identify where and how mastery can be accelerated.

**4) Establish keystone programs around keystone dimensions to cascade and accelerate the development of mastery in multiple dimensions.** Using safety as an example, we explain how companies can identify the mastery dimension that has an outsized effect on other dimensions. Programs can be designed around this dimension so that there will be cascading effects on the others, and multiple invisible-visible loops can be traversed for the systemic development and acceleration of mastery.

**5) Gamify mastery to sustain motivation for the mastery journey and to encourage professionals to stay in the industry.** Achieving mastery takes time and tenacity; staying motivated is key, but can be hard, even for the most dedicated. The mastery journey can be gamified to help technical professionals stay motivated, and to stem the leakage and loss of technical professionals out of the industry.

**6) Hack the digital age to accelerate mastery for the digital age.** Contrary to the perception that the digital age is all about the latest expensive technologies, our fieldwork saw technical professionals use every day and affordable technologies adeptly. There is thus a latent opportunity to explore how these technologies can be experimented and innovated with to accelerate mastery.

**7) Upgrade pilot plants into “petri-dishes” for future mastery.** Conventional pilot projects and testbeds are techno-centric and focus on technology adoption. Our proposed upgraded pilot plants focus on the interactions and human adaptability needed for future mastery. They can help to sense what needs to change as a result of the shifts accelerated by the pandemic. They can also help to test and integrate new and better ways of interactions between technical professionals of different disciplines, generations, seniorities and geographies that would advance their mastery.

# 1. Introduction

## 1.1 Background and Context

This study was funded by the Institute for Adult Learning to gain a better understanding of how we can obtain mastery at certain levels of our career/professional stage. In this report we draw on data collected between September 2019 and April 2021. We focused on technical professionals working in the Chemicals and Energy (CE) and the Precision Engineering (PE) sectors.

The impending digital transformation of the Singapore economy and society will bring forth new forms of learning and training. For the near future, it seems, there are more things that we need to learn and know (crossing disciplinary boundaries) and, moreover, we have to learn such skills at an accelerated pace to keep in tune with the speed of transformation. Hence, the policies point at issues concerned with lifelong learning and expanding learning pathways so we can 'upgrade', 'broaden', or 'deepen' our skills. At many educational institutes, for instance, courses within curricula are increasingly modularized so that different types of skills become 'stackable'. It also reveals an understanding of the responsibility of individuals to create their own pathways of skills development. Although it is not entirely clear whether the speed and efficiency in which learning occurs increases through such new programs, a more fundamental issue is that they may miss out on a crucial aspect of learning, namely, that it is not just a matter of successfully 'transferring' knowledge between individuals, but that learning is fundamentally a social process. With SkillsFuture, for instance, while giving individuals access to a broad range of new learning modules and skills, it is not clear how the diverse student populations learn the details, norms, practices, etc. that prevail within certain industries.

In January 2021, a new 10-year plan was put in place by Trade and Industry Minister Chan Chun Sing in a bid to grow Singapore's manufacturing industry by 50 percent.<sup>1</sup> The plan will not only increase global competitiveness of the manufacturing industry, but also give rise to more jobs for Singaporeans in the manufacturing workforce with the impending decrease in low-wage foreign workers. To achieve the 2030 goal, the manufacturing sector will need to maintain 12 to 15 percent of the total Singapore workforce, with higher skilled roles in place. This gives impetus for higher learning institutes and local talents in the manufacturing industry to further improve learning processes.

The COVID-19 pandemic has also shown us that we need to adapt to changing business conditions. For the purpose of this report, that was written in the midst of the pandemic, this also means that business conditions of top manufacturing firms have to be tackled.

The goal of this research, then, is to understand how mastery is impacted by digital transformation. Understanding what mastery in a digital age entails is important so that we can design for workplace learning environments that pay due attention to the concerns that we need to learn quicker and train broader but *without compromising the mastery and deep skills necessary to maintain a skilful workforce*. This is an important endeavour on which future policies and practice can be based in ensuring that the Singapore workforce continues to thrive while being propelled in a digital age.

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<sup>1</sup> Taken from <https://www.channelnewsasia.com/news/singapore/singapore-grow-manufacturing-sector-50-percent-2030-14037626>

## 1.2 Research Questions

The research conducted is exploratory in nature, primarily because the topics and concepts studied are not yet well researched. We started with a general literature review on the relationships between digital technology and human expertise (presented in the following chapter). Based on this and initial conversations we had with industry experts from the CE and PE industries, we designed a set of broad and open-ended questions:

- 1) What is the meaning of mastery for technicians in digitalising industries?
- 2) How do digital technologies threaten, challenge, or enable the development of deep skills?
- 3) How do technicians in Singapore's CE and PE industries define mastery? How do they currently train for this throughout the different phases in their career? (e.g. from polytechnic to workplace-based learning)

## 1.3 Methodology

The focus of this study seeks to understand the phenomenon of mastery in the context of technical professions in the CE and PE; a well-established Sunset Industry and a younger, emerging High-Tech Industry. Our choice for a focus on CE is twofold. First, CE has been and remains to be a sector contributing significantly to Singapore's economy. Within manufacturing, it is responsible for 29% of the entire manufacturing output.<sup>2</sup> Moreover, as it is such an important sector central to Singapore's economy, it also provides plenty of job opportunities for Singaporeans. Second, building CE plants are usually mega-projects; once a plant is built it will be there for decades. This makes it relevant to study how these plants are being updated and digitalised, and the result of our study will remain valuable for at least a number of years. This provides an interesting contrast with PE, which is a younger, emerging and, arguably, more dynamic sector. According to the Industry Transformation Roadmap for this sector, PE is positioned for enormous growth in the years to come.<sup>3</sup> The impact of digital technology will likely also be different in PE when contrasted with CE due to their internal differences. Finally, companies in the CE sector as well as PE usually cut across disciplines. Therefore, the research findings will, to some extent, be applicable more broadly to manufacturing in Singapore.

### 1.3A Methods

To address the exploratory nature of our research questions, we chose a qualitative study. Moreover, we applied grounded theory (Gehman et al., 2018; Glaser & Strauss, 2006) as a specific lens in the data collection and analysis. This allowed us to stay close to our research findings and concerns of participants in the industries. It also helped to assure that emerging insights, conclusions and recommendations were grounded in concrete data rather than in formulated, detached hypotheses to be tested. This approach, we believe, has been of specific value in making our research findings and recommendations applicable for Singapore.

To enhance the above even further, we wanted to approach our research with an 'ethnographic sensibility' (Neyland, 2008). To study something with ethnographic sensibility means to study a group of people in a specific cultural context to attempt to understand a chosen research phenomenon *through their eyes*. It concerns "the close study, over time, using participation and observation, of a group of people, with the emphasis on obtaining the insider view" (O'Reilly, 2005, p. 21-2). This facilitated the process of applying grounded theory. Moreover, it allowed us to offer an in-depth glimpse into two industries that are generally not studied ethnographically. While it may seem a stranger within such technologically oriented sectors, when properly applied ethnography is a unique methodology that is able to provide

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<sup>2</sup> Taken from the Industry Transformation Roadmap for Energy & Chemicals

<sup>3</sup> Taken from <https://www.a-star.edu.sg/Portals/94/downloads/pecoi2018/TseYong.pdf>

new observations and novel interpretations on which creative and applicable insights can be built (see, for example, Barley, 1996; Dalton, 1959; Fine, 2008; Jackall, 2009; Kunda, 2009; Ogasawara, 1998; Orr, 1996; Pachirat, 2011).

To understand those people you study and to be able to give a detailed description of their life-world with all its ambiguities, a quick visit is insufficient. Ethnographers emerge themselves for an extended period of time in the very world they are studying, to be able to not only see those things that strike the researcher as exotic or strange but also to uncover the mundane and routinized dimensions of organisational life (Ybema et al., 2009). Drawing on different methods, we immersed ourselves in the intricacies and complexities of technical professionals via a range of different methods.

First, we conducted about 250 hours of field observations. The aim of observations was to become aware of “*patterns* of behavior, artifacts, and knowledge that people have learned or created” (Spradley, 1980, p. 86, emphasis in original). This asked for simultaneous moves of getting close enough to gain an insider's perspective while keeping academic and reflective distance to put findings into context (Ybema and Kamsteeg 2009). We let the structure of our observations be defined by the daily activities of the people under study. This usually involved the researchers joining ‘a day in the life of’ a technician, zooming in on moments of learning or knowledge sharing and the use of technologies. We conducted these site observations at three locations:<sup>4</sup>

- 1) *Pilot Plant*, a highly digitalised pilot plant at a Polytechnic that trains students and working professionals in the CE industry;
- 2) *Box Builder*, a PE manufacturing company; and
- 3) *Cub Cleaner*, high-tech PE innovative start-up firm.

Observations allowed us to zoom in on what technical professionals actually do in their daily work, and how their work is challenged or facilitated by technology. This provided an important additional view to the interviews we conducted, as in interviews we were offered a look into what technical professionals say they do at work, and how they feel and think about this. Observations thus provided additional depth to our findings.

Moreover, observations allowed us to become more intimately engaged with the research topic and participants. For example, at *Pilot Plant* two researchers followed two classes of students for a whole semester during their engagements in the pilot plant. In doing so, the researchers developed some familiarity with technical terms and discourse of the community that helped tremendously in establishing rapport with interview participants subsequently. We also believe it contributed to getting closer to the actual concerns of participants because there were fewer misunderstandings when discussing the specifics of their field. Finally, observations often provided a surprising or novel view on issues. While we were not always immediately able to place their meaning and significance, we forced ourselves to take such observations seriously and interpret them via additional fieldwork. We thus engaged in a process of ‘abduction’ (e.g. Agar, 2010), whereby puzzles or questions stood central in the pursuit of going deeper into the subject matter. In the findings, we show this process of abduction by starting each section with an ‘exemplary observation’ that provided the starting point of that specific insight.

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<sup>4</sup> To retain confidentiality, all names of companies and individuals in this report have been anonymized.

We also conducted a total of 65 formal interviews with 62 participants (we had a follow-up interview with 3 of the participants). The goal of the interviews was to dig deeper into issues found in observations or conversations we had with the industries (Refer to *Annex A-C* for the interview guides used). The majority of interviews were conducted during the COVID-19 pandemic and related work-from-home arrangements. So, these were usually done via an online platform. This provided some challenges in establishing rapport during the interviews, as it is a less intimate and personal setting than face-to-face interviews. Fortunately, most of our respondents were keen on staying in touch with the researchers after the interview, so we were able to ask additional questions via email in case we missed out on something.

In addition, we conducted 5 focus group discussions with industry experts during different stages of the study to ensure that our emerging insights were relevant for the manufacturing industry. Three of these were conducted via an online platform during the pandemic, and two focus groups were conducted in a physical meeting when people were allowed to go back to the office again. These focus groups acted as important markers for the team to check whether the research and focus needed to be adjusted or not.

Lastly, we also organized 4 long-term engagements with 22 CE-major polytechnic students during their internship. We did this by following 4 groups of interns via WhatsApp. On a weekly basis, the research team would send a question pertaining to their internship and, more importantly, about the process of developing professional skills and attitudes. Interns would respond with their answer to the question, and sometimes discussions emerged naturally between students as well. We also checked in with these groups of interns on a regular basis via a videoconferencing platform to discuss any important questions in greater detail. We conducted 10 of such meetings, and these generally lasted about 1.5 hours.

We covered the different career stages of technical professionals by working with students, interns, early-career technical professionals (ECT), mid-career technical professionals (MCT), experienced technical professionals (ET), and retirees. Table 1 below shows a breakdown of the different categories.

No	Group Code	Career Stage	Years of Experience
1	Student	Student	-
2	Intern	Intern	-
3	ECT	Early-career Technical Profession	0-3
4	MCT	Mid-career Technical Profession	4-12
5	ET	Experienced Technical Profession	>13
6	Retired	Retired	-

**Table 1: Breakdown of Different Career Stage and Group Code**

The details of the all participants can be found in *Annex D-H*. We have provided each participant with a code to ensure anonymity. These codes show the career-stage of each participant as well as what industry they are active in, enabling the reader to understand with some more detail who said what. Table 2 shows a summary of the total number of participants for each of the different career groups.

No	Career Stage Group Code	Number of Participants
1	Student	4
2	Intern	24
3	ECT	13
4	MCT	15
5	ET	16
6	Retired	5
7	Industry Expert	3
8	Other Stakeholders	4
		<i>84 in Total</i>

**Table 2: Summary of Demographics of Participants by their Different Career Stages**

### 1.3B Data Analysis

All the data were transcribed and then analysed in NVIVO, a qualitative data software. We used the basic principle of grounded theory to come up with emerging theories based on the findings. It is important to note here that the analysis was not a separate step in the research process but happened simultaneously and iteratively throughout the study, highlighting the qualitative and inductive nature of our study (see e.g. Langlely, 1999 and Locke & Golden-Biddle, 1997 who have argued that the distinction between data collection and analysis in qualitative studies is often an artificial one). In our project, this meant we would have bi-weekly team meetings discussing the fieldwork conducted and data collected, exploring possible interpretations, challenging these interpretations, and come up with possible gaps or questions we wanted to include in subsequent interviews and observations. Further on in the project these team meetings happened more frequently as we were trying to make sense of the entire body of our data.

For the sake of clarity, the analysis process took three distinct steps which we will explain below. These steps are roughly based on grounded theory (Gehman et al., 2018; Glaser & Strauss, 2006) and we followed, in more detail, the analysis process as explained by Gioia, Corley and Hamilton (2012). In brief, Gioia et al. (2012) provide a specific approach to the analysis of qualitative data that aims to balance empirical richness and detail on the one hand and theoretical clarity on the other. Doing so, they propose different steps in the process of analysis in which researchers gradually move from engaging intimately with the data to stay close to research participants' interpretation towards larger, more abstract categories that describe and capture the research findings in more theoretical terms. We have adapted their approach, and specifically the data structure framework they offer (2012, p. 21), to move during our analysis from first-order codes to second-order themes, and finally to aggregate dimensions. Our data structure framework can be found in *Annex I* and visualizes, moreover, how our findings and how we present them in the report are grounded in the concrete data we collected for this study.

### *First-order analysis – staying as close as possible to the data*

As social scientists conducting qualitative, empirical studies, the analysis process is first and foremost characterized by our basic assumption that the world is socially constructed (Berger & Luckman, 1966). In our case, this meant that gaining access to the views and struggles of technical professionals with regard to developing mastery in a digitalizing workplace implied treating the technical professionals themselves as knowledgeable agents. In other words, in the first cycle of our analysis we tried to stay 'naïve' for as long as possible. Rather than forcing our own theoretical explanations or interpretations as scientists on the data, our role here was to stay humble in trying to understand our research participants' point of view. This approach is profound because it helped the research team to stay open to possible interpretations and actively challenge emerging explanations. This also helped in exploring explanations that we initially were not necessarily looking for based on our set of research questions (Wilkinson, 2013). For instance, while digitalization was one of the main themes we wanted to explore in our study, we were initially surprised to note that our informants generally did not talk too much about digitalization and technology when asking them questions about how they see expertise and how training and workplace learning happens. This made us reconsider an assumption with which we started the project – namely that digitalization poses a threat to expertise – and, instead, to focus on the more subtle ways in which our respondents talked about developing expertise.

In this first round we were thus not too concerned with finding clear theoretical explanations for our data and, instead, wanted to stay as close as possible to what our research participants had to say. In practical terms, this meant that we coded all of our interview, observation and focus group data rather openly and trying to use our informants' terminology as much as possible. So, if two distinct quotes about a similar topic were just slightly different, they would each get a separate code (e.g., "difference between working in the field and office" and "difference between operator and engineer"). Doing so, we forced ourselves to not interpret the data through our eyes as social scientists at a too early stage, as doing so might have blinded us to alternative explanations further on in the project. This, unsurprisingly, resulted in a huge number of unorganized codes. After this first round of analysis, we ended up with 506 distinct codes. The next round of analysis, then, was primarily focused on organizing this data by making it intelligible, thereby trying to categorize the data and trying to seek relationships.

### *Second-order analysis – finding similarities and differences*

Working with the codes we arrived at after the first-order analysis, in this subsequent phase of the analysis we were concerned with constructing linkages between data excerpts and codes. This primarily involved comparing different pieces of data and deciding whether or not they are to be treated as distinct codes or actually belong together to a similar theme. This, to some extent, is similar to Strauss and Corbin's (1998) notion of axial coding. This phase is different from the previous in that we now actively employ our own expertise as social scientist in making sense of our data. For example, here we would not shy away from more theoretically informed explanations in categorizing quotes and establishing links between distinct excerpts. In *Annex J* we have attached a screenshot of what such a data structure around a specific higher-level concept looks like (using the example of the code for digitalization in this case). Moreover, we would also establish links between different themes which we would then group together or not. The distinct codes "difference between working in the field and office" and "difference between operator and engineer", for instance, also discuss a similar theme in the sense that they both talk about learning from and between different hierarchies indicating potential issues regarding power struggles. Following this process of coding, we decided to instance that 'differences between generations' and 'differences between hierarchies' belong to a similar theme (e.g., section 3.3 in this report) while these are distinct from 'differences between disciplines' as this has a different theoretical explanation. It is also in this phase that we started thinking about higher level explanations of our data (only possible now because

the data has become more organized). These aggregate dimensions are more abstract and theoretically informed explanations and group together different categories explored in this second phase of analysis. Using the example given above once more, while ‘differences between disciplines’ is different thematically from ‘differences between hierarchies/generations’, on a higher dimension they both indicate how expertise is distributed between people, resulting in e.g., our aggregate dimension ‘expertise distributed in people-people interactions’.

#### *Third step – building a data structure*

Finally, after having identified the full set of concepts/codes, themes and dimension, we can engage in building a structure that best represents our data. This data structure (see *Annex I*) acts as a visual representation of our methodology and analysis and, more importantly, shows how our higher and more theoretically informed dimensions are grounded in concrete data – a pivotal component for demonstrating rigor in qualitative research according to Gioia et al. (2012). Moreover, in *Annex K* we show in further detail how our themes are grounded in data by providing more empirical evidence using exemplary quotes. The patterns and linkages identified here provided important grounds for writing this report. For example, when read from the right to the left (aggregate dimensions, themes, concepts/codes), the figure in *Annex I* resembles in some detail our Multi-faceted Mastery Model, although we have changed some of the wordings or decided to give more emphases to some specific themes at the cost of others in order to address the specific research goals and questions of the project.

This data structure acted as the basis on which we wrote the empirical chapters. It also provided the starting point for the more theoretical claims we make in the report. For instance, in attempting to provide more theoretical depth to our data we again engaged with the literature on expertise and digitalization. While this provided some hooks on which we could further our interpretation, we also realized that most existing work was insufficient because they start from a rather linear understanding of expertise which did not capture the distribution and fluidity of expertise that we observed and analysed. It is in this sense that our model is also of theoretical importance because it is not a predetermined model, we wanted to confirm deductively but one that is truly grounded in our fieldwork that captures the concerns and interpretations of our research participants.

## 1.4 Structure of Report

In the following chapter we provide the theoretical context for this study. We discuss seminal as well as recent work on expertise and mastery, with a specific focus on how this is challenged or facilitated by digital technology. We notice that the prevailing debate in this literature employs a conceptualisation of expertise that is less applicable to the modern workplace. We then spell out some of the implications of looking at workplace learning and workforce upskilling from this ‘outdated’ view and provide some suggestions on how the concept can be updated. This will be given more flesh in the empirical chapters 3-5. Chapter 3 focuses on specific interactions we found in our data *between people*. These interactions show how mastery is distributed between social groups, and this covers the development of deep domain fundamentals, collaborating across disciplines, and learning between generations. Chapter 4 looks at how expertise is not only distributed between people but now, increasingly, also *between people and technology*. In this chapter we look at this in the context of technology and human competencies, and in the context of expertise in specific work environments. Chapter 5 discusses our research findings in the context of the COVID-19 pandemic. While this was not the initial focus of our study, it was a prevalent topic during our fieldwork and interviews. It is also directly related to issues pertaining to expertise and technology - and most often of these two in combination. We found it important to include these insights into the report because they show the applicability and importance of our research findings. Based on the presentation of our findings, we finally formulate a range of recommendations in chapter 6.

## 2. Literature Review

Expertise, and what it entails, is one of the most enduring questions within the academic disciplines of (workplace-based) learning and development, and in organisation and management studies (Sandberg et al., 2017). What it means to do something skilfully and how to develop competencies within an organized workforce has for a long time stood centre stage as a way to think about economic, as well as societal progression. Already in *The Republic*, written in 360 BC, we read how Plato worries about the question of expertise in the context of soldiers, and of the nature of their skills for guarding the city. Even in Frederick Winslow Taylor's work on 'scientific management', often touted – and with good reasons – for its dehumanizing approach to work, we do find an interest in the competence of human workers. While the focus of his project was primarily on increasing business efficiency and process automation, at the heart of this we see how this relies on skilful workers:

*It is only when we realize that our duty, as well as our opportunity, lies in systematically cooperating to train and to make this competent man [sic], instead of in hunting for a man whom someone else has trained, that we shall be on the road to national efficiency (Taylor, 1911, p. 6)*

Besides putting the human worker and the management of their tasks central to delivering productive output, Taylor also points attention to the role that companies, and even national efforts play in bringing this into fruition.

Taylor wrote his work and developed his management approach in an era of rapid technological developments, especially concerning the mechanisation and standardisation of manufacturing work. Fast forward to 2021, and we find ourselves amidst a very different, albeit equally disruptive and transformative period of change. Coined as the Fourth Industrial Revolution (hereafter, 4IR), we see an increasingly complex and intimate integration of physical and digital (cyber-physical) systems and technologies (Schwab, 2016). Discussions about the increasing use, application and efficiency of digital technologies and the speed of digital disruption in all spheres of life has been the centre of attention in not only academia but also the domain of public policy and even everyday conversations. In Singapore, for example, Industry Digital Plans have been developed to “provide SMEs of various sectors with an easy-to-use, step-by-step guide on the digital solutions to adopt at each stage of growth and the training programmes to enhance employees’ digital skills”.<sup>5</sup>

Much of the debate has taken a technologically deterministic angle from which diverging predictions are made on how technologies will radically transform the way that current workplaces are organized and how people conduct their work. Although the impact of technology on the future of work is not a new phenomenon (e.g. Zuboff 1988), recently the idea seems to have started a life on its own: claims are made about an upcoming Fourth Industrial Revolution transforming the nature of jobs (Schwab 2018) and heralding the end of an era of specialist professions and practical expertise (Susskind and Susskind 2015). Many reports are written to assess the consequences of a digital revolution on the workplace by big consultancy firms such as Deloitte, PricewaterhouseCoopers and McKinsey, as well as agencies like the International Labour Organisation (ILO 2017) or the World Economic Forum (WEF 2016). These trends have only been accelerated and been brought into sharper view during the COVID-19 pandemic. For instance, where a large part of the workforce was forced into remote working because of social distancing measures during the peak of the pandemic,

<sup>5</sup> Taken from <https://www.imda.gov.sg/programme-listing/smes-go-digital/industry-digital-plans>

it is estimated in recent reports that this trend is likely to stay and that new forms and types of work will emerge (e.g. McKinsey 2020).

Although the predicted consequences of disruption are diverging and range from the real possibility of impending mass-unemployment (Ford 2016) to more moderate and nuanced observations that automation and new technologies will also create whole new industries (Autor 2015; Wajcman 2017), the large majority of studies and reports converge on one element: the centrality and importance of continuous learning and training. It is generally understood that the current pace of technological disruption requires new forms of training and an adequate skill set allowing individuals, as well as whole societies, to remain relevant for the new digital age. This observation has also been set centre stage in the discourse on economic development and technological transformation in Singapore. In fact, education and technical training have always been closely connected to the nation's transformation, and it has offered ways through which Singapore has been and is able to prosper economically as well as socially. Historically, this has been done by creating and maintaining an employable workforce fit for each subsequent period of industrialisation in the nation (Loh and Farran 2015; Ng 2013; Varaprasad 2016). More recently, SkillsFuture was initiated as "a national movement to provide Singaporeans with the opportunities to develop their fullest potential throughout life, regardless of their starting points".<sup>6</sup>

In sum, the question regarding what expertise entails and how it can be developed remains as important as it has historically been. Especially so, because skills once regarded as belonging to a human realm are now increasingly being augmented by technology.

Yet, we observe a problematic assumption in both the literature on expertise and in policies that are often based on these theories. While we readily assume that the workplace is transforming rapidly and significantly, we have a harder time thinking about what constitutes human expertise in an equally transformative sense. This is problematic for two reasons. First, assuming that expertise is an isolated and stable phenomenon in a world of rapid change fails to account for how the two are intimately interrelated. Expertise does not follow change. Change and technological innovation are a result of experts, and transformation of workplaces puts new demands on expertise. Second, and perhaps more fundamentally, if expertise is indeed a stable and enduring concept then we find ourselves in a particularly precarious position. Because, if the above were the case, how can we ever catch up with the pace of technological change?

The main aim of this report is to show that the assumption above is incorrect. Expertise in a dynamic and disruptive context is equally dynamic and potentially equally disruptive. The concept of mastery in and for a digital age thus needs to be updated. As argued in the previous sections of the report, our findings show that mastery in a digital age can be characterized as being *distributed*, *multi-faceted*, and by its increasingly *invisible* nature. We describe these elements in detail in the findings, and sketch out the contours of what this means for Singapore's workforce development in the recommendations. For the remainder of this chapter, we lay the ground on which we will base these claims. First, we briefly highlight some of the characteristics of digitalisation and digital technology to show why our thinking of mastery must change accordingly. Second, we then explore how expertise is usually conceptualised, why this has now become insufficient in thinking about workplace development, and how we can start thinking about a new formulation of the concept of mastery that is more firmly grounded in technological and societal developments.

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<sup>6</sup> Taken from <https://www.skillsfuture.gov.sg/AboutSkillsFuture#section2>

## 2.1 **What is different with digital technology?**

Technology has, for decades, been a source for organisational analysis (e.g., Perrow, 1967) or for examining industrial relations and how technology shapes the labor process and ways in which people work (e.g., Braverman, 1988). What is different now, however, is a number of qualities that constitute emerging technologies in comparison to older, existing technology. We will expand on some that are most pertinent to our report below.

### **Digital technologies are ‘intelligent’ technologies**

First, emerging technologies are becoming increasingly intelligent technology. Previous technology used to be ‘machine-like’, i.e. still controlled by an operator, and this had primarily an impact on the transformation of work practices of the labouring body. Repeating popular discourse or analogies, such technologies were often said to lead to some sort of alienation from work with human workers becoming a mere cog in the machine, subservient to what the machine dictates. In a sense, previous technology was threatening because they mechanically replaced human, bodily functions.

In comparison, as Bailey et al. (2019) elaborate, emerging intelligent technologies do much more than merely automating work. Advances in AI, robotics and sensors, augmented reality and data analytics offer the potential to not just impact the human body but also the human mind and senses. For instance, in healthcare the introduction of robotics has vastly changed how surgeons work and what is required of them in terms of skills and knowledge. Here, rather than replacing the human body, we see a much closer relationship between the human and the machine and one that is based on augmentation more than automation with a blending of sensing capabilities (Sergeeva et al., 2020). More than reducing the body to mechanically providing the input to a machine (“pushing the buttons”), such technologies impact the qualities of perception of haptic, visual and auditory senses. In their analysis, the authors argue that, while the robot only directly changes how the surgeon works, such augmentation impacts far beyond just the practices of the workers and redefines issues such as coordination, occupational roles and responsibilities, and providing new interdependencies (Sergeeva et al., 2020).

The issue of how technology augments, complements, and impinges on human expertise were very prominent in our findings too, as we will show in our findings. This is not just a matter of changing work practices but is (or should) also be of prime concern for how we think about learning. For instance, such emerging changes are usually not yet incorporated into formal learning and training practices, potentially leading to people lagging behind more than necessary. Beane (2019), for instance, has shown how such a gap between workplace realities and training programs may lead to novel practices through which people learn informally. He, moreover, warns that because such new practices are often not formally approved but crucial nonetheless, this ‘shadow learning’ may ultimately lead to troubling outcomes such as hyper-specialisation or a decrease in the supply of experts in a particular workforce.

Looking into this matter offers an opportunity for understanding how people learn in a digitalising context and how to design the right interventions. It also shows it is important to provide the right policy context that supports rather than constrains this.

### **Digital technologies work on a different scope and scale**

Current advances in Big Data and technologies that make use of this (e.g., AI, analytics, algorithms) redefine the *scope and scale* of how emerging technologies penetrate organisations, industries, societies, as well as the global landscape of work. This automatically also redefines the scope of workers and the scope of work tasks that have to be mastered anew. It is estimated that in the past few years we have generated more than 90% of all the

data in the world (Marr, 2018), and this percentage is still growing exponentially. The availability of data has given rise to a whole new range of technologies that partake in the quantification of many aspects of our life, specifically so by means of algorithmically mediated technology (i.e. anything running on code or software).

This provides not so much the augmentation of human sensing or bodily capabilities but of human thinking capabilities. For instance, a recent study by Pachidi et al. (2021) has looked at the implementation of data analytics and algorithmic decision-making in a sales department in a telecommunication organisation. Their study highlights that sales and identifying sales opportunities, which originally focused on the in-depth knowledge of customers and building strong relationships, increasingly became a matter of predictions based on data analytics. This immediately impinges on what it means to be a good sales professional, and how they draw on their existing knowledge in order to make sense of the new skills required by the job, such as interpreting data to come to meaningful decisions.

A complicating factor here is that the data on which these technologies run are far from objective (e.g. O'Neill, 2016). So, while the promise underlying data analytics is that technology can automate human work processes, the reality is much more nuanced. While human expertise possibly relies less on gathering data and crunching the numbers, a new skill emerges that becomes much more important: the data must be interpreted by human brains and bodies to see and assess their effects on workplace practice. So, professionals have to become an expert in verifying the data and noticing and/or fixing the bias in them. In other words, these technologies redefine expertise and this must be done carefully while taking into consideration if these effects are warranted and desirable (Pachidi et al., 2021, p. 28).

### **Digital technologies intensify transformation of expertise**

Raisch and Krakowski (2021) discuss the above in the context of AI by reviewing three recent high impact business books on the impact of AI. Notably, all three books (Brynjolfsson & McAfee, 2014; Daugherty & Wilson, 2018; Davenport & Kirby, 2016) emphasize augmentation over automation and link it to superior business performance. This leads to our third point, namely that emerging technologies afford an *intensification* for the depth with which work becomes driven by them and with which workers have to master new skills. From a critical perspective and by a theoretical framing around paradox, Raisch and Krakowski (2021) posit that augmentation and automation cannot be understood separately and in fact go hand-in-hand: machines outperform human workers in some cognitive tasks (e.g. crunching massive amounts of numbers or discovering important correlations) and human workers outperform machines in other respect (e.g. in making sense and interpreting data or in providing important context).

This builds on but also goes beyond human-machine interactions described several decades ago by e.g., Lucy Suchman (1987, 2007). With emerging technology we see a further blurring of boundaries between the human-machine dichotomy and a novel form of collaboration emerges. This approach is new and exciting, builds on previous work conducted by the Lee Kuan Yew Centre for Innovative Cities (*LKYCIC*) on a government-linked organisation in Singapore, and will have important implications for what mastery is and how we can train for this. Moreover, it may lead to new and intriguing questions on responsibility and litigation, such as whether or not the developers of devices or intelligent software share the responsibility for the consequences of potential breakdowns.

### Digital technologies increase the pace of transformation

Finally, the *pace* of digitalisation increases rapidly. This has only been fuelled by the current pandemic, which has revealed our dependence on digital technology, what it allows us to do (differently), but also its limits on how we can do our work well. Recent reports have started talking about a 'post-pandemic workforce' (e.g. McKinsey, 2020) and it is expected that the pandemic has accelerated trends already underway. For instance, Zolas et al. (2020) found that the implementation of a specific business technology often implies the adoption of many other technologies too, as these build on each other and need a specific infrastructure in order to function. Moreover, they found that worker exposure to such technology may be much higher than the firm exposure, which suggests that its impact on expertise and mastery becomes key (Zolas et al., 2020).

Bailey et al. (2019) discuss this in the context of technology diffusion and adoption, arguing that emerging technologies define and keep redefining how we work. This very likely also changes not just how we see expertise but how we must continuously change our expertise while not forgetting what we have learned before. In a strange sense, the pandemic has been a global experiment in which we were all forced to become experts in new technologies and ways of working, overnight! Besides showing us what technology can do (most of us were able to continue doing our job via these technologies) it has also revealed what is being left out when work and collaboration is technologically mediated. There are limits when working and learning, as a social and interactive endeavour, move to a digital realm.

This has brought into sharp focus what technology can do (and what should be digitalized) but also, perhaps more importantly, what should remain in human hands and minds. Hadjmichael and Tsoukas (2019) look at this in the context of tacit knowledge. They first question whether advances in e.g. AI have made concepts such as tacit knowledge redundant, especially because artifacts can now function 'intelligently' independently. What is more, technology can learn and improve without apparently much human intervention needed (Faraj, Pachidi & Sayegh, 2018). Yet, such intervention is critical, as technology can only use the data that is available and AI can detect patterns but cannot capture the tacit knowledge that is involved in making good or right decisions. Hadjmichael and Tsoukas (2019, p. 54) thus maintain that tacit knowledge is, perhaps now even more than ever, crucial to being an expert practitioner: a master is a contextually sensitive practitioner, who is able to judge the relevance of decisions made by technology and make sense of data and computations. The link between technology and work is thus a complex one; technology affords, facilitates, and helps to innovate but it also challenges, changes, and disrupts. As has been shown in previous studies, technology (and digitalisation at large) changes how work and work practices are organized (Aroles et al. 2019), how work is being done and what skills are deemed important (Gekara & Nguyen, 2018), how we use our bodies in work and how technologies may disrupt professional and occupational boundaries (Sergeeva et al., 2021), and how this can transform what is considered as valuable knowledge (Pachidi et al., 2021). The above all indicates that expertise, what it entails, and how it can be developed remains fundamental questions in the literature. In fact, one could argue that it is the specific nature of digital technologies, their pervasiveness and their interconnectedness, that makes these questions now more important than ever. Finding an answer to them may help guide our thinking on what future of work we want to shape and produce.

## 2.2 Updating mastery

The review of the literature above provides an update to how 'mastery' in all its breadth is currently being discussed. We think the update is especially relevant to think productively about what can be done differently and better in terms of organisational or societal policies. As recent work has highlighted (Poon et al., 2020; Raisch and Krakowski, 2021), digital disruption can be seen as a threat and as an opportunity; thinking about it in nuanced ways,

taking into equal account the quality of technology and human beings and the ways in which they are interrelated, may offer a way forward that fulfils both the economic needs of a society and the well-being of its people. More importantly, it tells us that expertise, what it entails and how it can or should be developed is at a crossroads. We cannot think of this in traditional terms anymore, e.g., such as the crafts- and skills-based work activities described by Lave and Wenger (1991). The interconnected nature of technologies, people and places combined with the rapid pace of change must be taken into account when answering what mastery means in a digital age.

The main assumption in literature on expertise is that the development of mastery follows a range of steps or phases. One can gradually progress along these steps through time and experience, and develop skills or a profession from novice to master. The work of Lave and Wenger (1990; Wenger, 1998), for instance, has been seminal in showing how learning is a social rather than intellectual process. Their work marked a tremendous update to learning theories. Yet, the workplaces they studied are not representative of the average, modern workplace. Their conceptualisation of a workplace is centred around the communities of practice created in a space (Wenger, 1998). The word “communities” implies that work, and learning, is inherently social in nature, consists of interactions between the people belonging to that space. As one progresses in their career, the individual develops and hones his/her domain knowledge and skills by learning and executing existing work practices through co-participation (Billett, 2001). One thus gradually moves from the periphery to the core of the community through participation and learning the implicit rules, values and norms of a profession (Lave and Wenger, 1991). A key assumption here is that one can gradually progress to the core of a community through extended exposure to a profession. Currently, however, workplaces are far less stable than those described by scholars such as Lave and Wenger, making some wonder whether the idea of a stable and well demarcated ‘community’ is still applicable (Pyrko, Dörfler & Eden, 2019).

Likewise, the work of Hubert and Stuart Dreyfus on skill acquisition has been equally seminal (1988, 2005), this time by situating learning as a more phenomenological inquiry. One of the more important lessons we can learn from their work is that developing expertise entails becoming a more intuitive practitioner. For a novice, everything is new and stands out as something to attend to. For an expert, explicit rules have become much more implicit and practitioners make intuitive choices based on tacit and embodied knowledge rather than deliberate choices based on rules and procedures (cf. Willems, 2018). Yet, also in their account we notice an assumption of steps, or stages. While this may be relevant in examining expertise as a phenomenological endeavour for explaining how individuals master a certain practice, it may be less applicable in examining expertise in a landscape where the boundaries of that practice continuously change and even shift (Dall’Alba & Sandberg, 2006). Moreover, the unintended consequences of thinking of expertise as a succession of steps to be taken is problematic because, once the level of master is reached, learning is apparently less central (Yanow, 2015). This is counterintuitive when compared to current discourse on digital transformation where everyone, from every age and every rank, will need to learn or re-learn their practice.

A closer look at the work of technical professionals is in order here. Scholars studying technicians and engineers (the focus of this report), while not *explicitly* contributing to theories on learning and expertise, have implicitly, however, challenged some of these core assumptions. We briefly review this literature next, after which we set the stage for presenting our findings and how they contribute to these ongoing debates.

### Technical work and the fluidity of expertise

Over the past decades, technical work has come to constitute an increasingly larger segment of the professional workforce (Barley, Bechky, & Nelsen, 2016), both globally and in Singapore. Technical work comprises, for instance, engineers and what is often referred to generally as technicians. As Barley and Orr (1997) note, the work of these people can be characterised as standing between something a craftsman does and what a scientist does. However, while not belonging to either of these more traditional occupational categories, engineers and technicians have become important occupations in their own right. They are crucial actors in the post-industrial era, where much of the manual work has been transformed into knowledge work, with companies offering services as much as producing products (Drucker, 2011). As such, they have come to exemplify the division of labour with occupations becoming ever more specialised, a trend fuelled by both globalisation and the implementation of more complex technologies, among other things.

As Barley (1996) argues, this 'technization' of work, as Barley calls it, and of the workforce implies that people such as technicians and engineers must be able to navigate different realms or technical worlds. On the one hand, they must have intimate knowledge of the material tools and technologies they work with and need to operate. The goal of their operation is to transform such material entities into symbolic entities, such as data, test results or images. So, on the other hand, engineers and technicians must also have knowledge to work with, interpret and communicate these more abstract representations (Zuboff, 1988). For these reasons they fulfil a central position within many organisations. They often act as brokers between those with more specialised jobs (having to use the technology without knowing all the technical details) and those belonging to a technical community (knowing the technical details of a technology without really understanding how it is used). This gap is often bridged by technical workers who can translate knowledge and share meaning from one side to the other (Bechky, 2003).

Zuboff (1988), in her study and comparison of different paper mill plants, has looked at how one specific plant computerized parts of its production process. Technicians and engineers working at this plant increasingly had to perform their tasks in control centres rather than the actual plant. Looking at the relationship between Information Technology (IT) and work, Zuboff describes how technologies shape the experience of work and how this experience, in turn, shapes how technology is used and implemented. This shows that technology implementation is not simply a top-down process that can be designed and controlled as to the wishes of management; technology changes work practices and the communities of practitioners that are affected by these changes have some discretion and power in shaping how technology is used. In her study, for instance, the reaction towards IT was quite different among different groups of workers. Older workers experienced difficulties with reading and analysing the data sheets that came to constitute much of their work due to the introduction of computers. Younger workers, on the contrary, were better able to work with data because of being exposed to performing tasks on computers at a younger age. However, they lacked the practical experience of the physical plant, something older workers had intimate knowledge of. This is an old problem and one that has not been solved yet, and one could argue it is becoming even more important with an ageing workforce and given the rapid digitalisation of workplaces.

The link between technology and expertise is a complex one; technology affords, facilitates, and helps to innovate but it also challenges, changes, and disrupts. As has been shown in previous studies, technology (and digitalisation at large) changes how work and work practices are organized (Aroles et al. 2019), how work is being done and what skills are deemed important (Gekara & Nguyen, 2018), how we use our bodies in work and how technologies may disrupt professional and occupational boundaries (Sergeeva et al., 2020), and how this

can transform what is considered as valuable knowledge (Pachidi et al., 2021). The above all indicates that expertise, what it entails, and how it can be developed remains fundamental questions in the literature. In fact, one could argue that it is the specific nature of digital technologies, their pervasiveness and their interconnectedness, that makes these questions now more important than ever. Finding an answer to them may help guide our thinking on what future of work we want to shape and produce.

The work of Zuboff and Barley and colleagues cited above may seem dated, especially from a technology perspective. Yet, the questions they asked still exist and are now more relevant than ever: the technization of work, termed by Barley, is continuing at full speed while the means to remain or become productive and relevant actors within this new world are in many respects lagging behind. The 4IR has catapulted us into a world of Big Data and many decisions are based on these data and algorithms supporting them. Moreover, the COVID-19 pandemic has laid bare some vulnerabilities. We had to learn the hard way to see how dependent we are on technology, specifically technologies that make working from home and operating production processes from a distance possible. In many ways we are facing a new reality in which technology has become a cornerstone for organisations to survive, while we lack a readily available workforce that has the expertise and skillset to thrive in this new reality. Disruption forces companies and individuals alike to innovate and upskill, but becoming a competent and skilful actor typically happens at a slower pace than disruption allows.

We thus need to rethink how we learn amidst disruption and what it means to be an expert in a digital age. In this report, we say that mastery in a digital age is characterized by its distributed, multi-faceted, and invisible nature. One of the ways in which mastery has become distributed is between and among groups of professionals. As we will show in the findings, developing mastery transcends beyond development of expertise in one's own domain. As work becomes increasingly interconnected and complex, it also means that we must tap into the expertise of those belonging to different disciplines and different generations. Despite the prevalence of digital devices and technology in the CE and PE industries and despite an enormous focus on digitalisation in companies and policies, our work has found that interactions at work and the ways in which people become an expert in a certain profession remain in the interactions between individuals. Mastery is thus multi-faceted because people need to know and learn their domain from the inside out but also, from a multitude of different perspectives, from 'the outside in'.

In the chapters to follow, we present our research findings and show how and why mastery in a digital age is better understood as being a phenomenon distributed among a wide web of multi-faceted human and non-human actors. Moreover, our findings illustrate that with digitalisation comes a process of expertise becoming less visible (i.e. though it remains crucial it becomes more embedded in sociotechnical systems). These insights shape the recommendations we provide at the end of the report. Mastery in a digital age, we argue, centers on bringing what has become invisible back to our attention and pulling together the distributed, multi-faceted nature of expertise.

# 3. Multi-faceted expertise distributed across people-people interactions

In this section, we identify three main areas of people-people interactions in the workplace that one has to develop in order to attain mastery in the digital era. They are listed as follows:

- 1) Develop intra-personal expertise through effective experiences.
- 2) Develop inter-disciplinary expertise.
- 3) Learn through inter-generational expertise and across different hierarchies and seniority.

## 3.1. Develop intra-personal expertise through effective experiences

A technical professional's grasp of the foundational skills in their domain is fundamental to their profession and their subsequent ascent to mastery. This is a given – so much so that the traditional linear ladder analogy of mastery is built on this – and the premise upon which all skills building initiatives are built.

But because it is a given, it risks being taken for granted as the ground beneath this premise shifts in the digital age. Our findings saw technical professionals worry that digitalisation threatened the development of these foundational domain skills, and could even be detrimental to the core of their professions.

Developing mastery in the digital age thus demands that we renew the premise through emphasising effective experiences (not simply years of experience) that:

- 1) Deepen domain fundamentals;
- 2) Achieve professionalism; and
- 3) Ignite and instil élan

### Digital technologies could threaten foundational domain skills, professions, and mastery

In our research findings, many respondents referred to the more 'traditional' view on expertise and training that we elaborated on in the introduction and theoretical part of this report. Noteworthy, however, is that an emphasis on key foundational domain skills was, by our participants, primarily mentioned in the context of digitalisation. Rather than assuming that these core skills make one automatically progress through the stages of mastery, it seemed that it was exactly digitalisation that posed a challenge to the development of such skills. Given that digital technologies perform many of the core skills on behalf of professionals.

One way to counter this threat is to ensure that technical professionals invest in enough experiences over the years to hone their "intuition". For technical professionals themselves, the common criteria for one to be considered an expert is someone who possesses "intuition" that is *"tuned so finely that the minute there is an issue, instead of going through an entire list of problems that can be contributing to this (problem), they can just point at one and say this is most likely what it is"* (Participant 07, ECT, CE). More often than not, the intuition is developed through their cumulative experiences of spending over "10, 15, 20 years" in the industry which has allowed them to hone their technical knowledge and skills. These experiences can range from common issues to rare events such as *"explosions and giant equipment tripping due to electrical faults"* (Participant 07, ECT, CE).

### Emphasising effective experiences (not just years of experience, and how are they similar/different)

While a common line of thought as expressed by our participants was one aligned with the idea that experience and time leads to the attainment of mastery, some also challenged this correlation. Participant 38 (MCT, PE), for example, questioned whether time is always a good indicator for determining someone's expertise:

*I can be an engineer, but I can be a part time engineer who's working only weekends. I could be working for 7 years but I'm only working on weekends. So I could say I'm [have] 7 years' experience. Versus someone who has – who's working in the same industry but doing it 24/7. Maybe this guy doesn't stop. Probably that 2 years of experience is – brings him to a higher level of mastery than a person of 7 years' experience.*  
(Participant 38, MCT, PE)

Participant 38 (MCT, PE) highlights how not all workplace experiences contribute equally to one's learning and expertise development. He explains that the reason why someone with only 2 years of experience could be put more competent or could attain mastery more quickly compared to someone with 7 years of experience is because of their "concentration of efforts within the 2 year time span" (Participant 38, MCT, PE). Indeed, it is one's concentrated efforts and *how* they spend and make use of their time throughout the different experiences in their career that determines the quality of the experience they have. These particular types of experiences that are rich in value are those that are made up of deliberate practice and active learning. The concept of concentrated efforts is similar to the idea of 'deliberate practice' put forward by author James Clear (2016). He shares that "Deliberate practice is a special type of practice that is purposeful and systematic. While regular practice might include mindless repetitions, deliberate practice requires focused attention and is conducted with the specific goal of improving performance and developing intra-personal expertise." (Clear, 2016) Note, however, that with sufficient deliberate practice (e.g. of a work task) one develops proficiency and expertise which, ultimately, means that the expert does the work with less focused or conscious attention (e.g. Dreyfus & Dreyfus, 2005). While this is indeed a quality that sets experts apart from novices and allows them to make more fine-grained and intuitive decisions, it is important to highlight that this is only possible after having had the chance to be exposed to enough deliberate practice. Moreover, it would also be wrong to assume here that experts themselves do not require any form of deliberation, as if they would never make mistakes anymore (cf. Yanow, 2015).

Participant 30 (ECT, PE), shares this sentiment by suggesting that the way and quality in which someone invests effort in a task is perhaps more important than the time one spends doing it:

*I would say it doesn't mean that you've been in the company for very long that you'll develop mastery or expertise. Or actually expertise or mastery would be a mindset where you continuously try to understand the product day in and day out. Because if I give you somebody who's been there for 20 years and then he or she has been doing the same thing 24/7 and has not been asking why or what is the importance of that process then, I wouldn't say that they have developed mastery in it. Versus somebody who has joined the company, and has the mindset that okay I want to know what happens before my process and what happens after my process. And what is the importance of my process in the whole process flow. Then I would say, you are on the path towards developing mastery. (Participant 30, ECT, PE)*

Here, participant 30 (ECT, PE) also highlights how one's initiative and the extent to which they are actively learning determines the value of their experience and their attainment of mastery. Hence, our findings have shown that the attainment of expertise is not always determined by the years of experience that an individual has at the workplace. Instead, we need to look beyond just the length of one's experiences and study the quality of one's experiences, which

we coined as the term “effective experiences”. Effective experience refers to work experience that effectively made an impact in work performance and develops mastery. In the remainder of section 3.1 we will expound on factors other than time that contribute to the attainment of intra-personal expertise.

### 3.1A Deepen domain fundamentals (having strong foundations and recognizing links in the system)

*The teacher emphasizes the importance of a meticulous ‘line-setting’. They talk about what line-setting is, and compare it with line-tracing. Apparently, line-tracing is getting a sense of the whole system of a plant by following all the lines (i.e. pipes, connectors, valves, etc.) via the maps and drawings, whereas line-setting involves the actual physical tracing of the plant. The teacher elaborates: “You have to be aware that if you close a valve here something else happens there. Things are connected in a system like this, and you must constantly ask yourself what your action or inaction does to this system”. (Fieldnotes, Pilot Plant, 29 Oct 2019).*

Deepening domain expertise involves being proficient in everyday tasks and completing one’s job responsibilities effectively. To excel in this area requires one to have strong foundations in basic principles of engineering and to be able to understand, recognise and appreciate links in the system. This is even more important now, because digital technologies have the tendency to obscure expertise – tasks that have been automated or augmented make the domain fundamentals needed to perform them less visible to the core manufacturing process and thus *appear* less central (i.e. out of sight, out of mind).

#### **Strong foundations improve judgement, differentiate experts from the mediocre, and contribute to designing new, sophisticated technology**

One must first establish strong basic foundations within one’s domain. Core subjects that appeared to be highly applicable in both CE and PE industries are the Sciences and Mathematics. This was emphasised in our interviews with professionals from both industries. In fact, the professionals repeatedly emphasised this *especially* in view of increasing digitisation.

Participant 05 (Student, CE) reflects on how these often foundational core skills remain important for practical settings:

*So in chemical engineering there are, so there are a few main principles. So there is this thing called mass balance, it’s like the concentration of mass so we keep track of what goes into the unit. So let’s say you are dealing with a reactor, you keep track of what is going in and what is going and then from there we can calculate how much of the reaction, or how much of the reactor has been transformed into the desired product. So that is called a mass balance (...) So in like, in the industry or during my internship I actually make use of this simple principle to check if there have been leakages or stuff so that if there is some leakage, and some significant leakage, the mass balance will be violated (...) I was actually quite surprised these simple principles are adopted by the process engineers to check if everything is working fine. (Participant 05, Student, CE)*

Similarly, participant 09 (ECT, CE) mentions how such core knowledge contributes to your professional identity as an engineer:

*In terms of engineering, we learn ideal gas law for example, like this kind of thing, we need it, we need it day to day like on my job. You need to know it on your fingertips you know. Like the moment people talk about gaseous streams you need to have that*

*mentality because, you know we are engineering trained right. So that knowledge is crucial and it helps you with your day to day troubleshooting as well.*  
(Participant 09, ECT, CE)

It is evident that basic principles of engineering are important and relevant at the workplace as they are applied daily to check for malfunctions and ensure that the machines are operating smoothly. Moreover, engineers are expected to have these basic principles at their “fingertips” and be so familiar with these concepts so they are able to apply and understand fundamental engineering principles when the need arises. Beyond simply having factual knowledge one also needs to understand how to apply them in a practical context.

A similar sentiment was prominent in our interview with participant 41 (MCT, PE) who shares that what separates an expert technician from an average technician is their depth of knowledge:

*For somebody that has been working on a particular area for a good 20-30 years, when we ask them questions, they will be able to articulate even the theoretical fundamentals. So for example if I were to go up to someone who's been doing the same thing for 30 years, and I ask him a particular question, he will basically be able to tell you why the particular engine is designed that way. So they know the fundamentals, I think that's the difference between a mediocre engineer and the specialist. Depth of knowledge.*

Engineers that stand out in the industry or those that are regarded as experts are strong in their foundations and basic engineering principles. Beyond being integral to their everyday work, our findings show that having strong foundations in engineering principles was repeatedly emphasised *especially* in view of increasing digitisation. As participant 14 (MCT, CE) explains, with digitalisation becoming increasingly prevalent there is a tendency to emphasise the “sophisticated tools” at the cost of forgetting the basic principles:

*From a manufacturing plant perspective, you need to get your engineering, your math, and your chemistry correct. Then, you can use sophisticated tools to deliver the results. So, as the tools become more complicated, then we must remember that, always to go back to basics. Like the, ask the why, and things like that. Why, why this one doesn't work, why why why and why. And, so that would, that is where all your basic knowledge would come in.* (Participant 14, MCT, CE)

He also cautions about the pitfalls of engineers forgetting their basic chemistry. *“No matter how sophisticated the tool is, you cannot, and probably should not replace it with good engineering judgement.”*

While participant 14 (MCT, CE) mentions the prevalence of ‘sophisticated tools’, it is important to note that no matter how developed or sophisticated these tools are, they are ultimately built on foundational engineering fundamentals. A, an experienced technician in the PE industry who has been exposed and trained in a variety of new cutting edge technologies such as 3D printing, shares the following:

*The foundation of traditional technologies, they make up the foundation of any new cutting edge technology. So for newer cutting edge technology to emerge, there has to be some form of foundation. So therefore this foundation has to be instilled in – has to be instilled in engineers.”* (Participant 14, MCT, CE)

His responses highlight the unchanging relevance of engineering foundations in the industry. Sophisticated tools and cutting edge technology are not only built on basic engineering principles but these principles will continue to be hallmarks of the engineering industry even in the future. Hence, having strong foundations in these basic engineering principles are and

remain key to attaining mastery in the digital age. Learning new, digital skills should not be done at the cost of such foundational knowledge.

### Understanding, recognizing and appreciating links in the system: knowing how and what you do connects to and affects others

From our fieldwork it was apparent that putting foundational domain knowledge and skills into practice almost always was a collaborative effort in the field, plant or manufacturing floor. This was highlighted by participant 05 (Student, CE) and participant 35 (ECT, PE):

*Because each of the engineers will likely be responsible for just one part of the plant and there will be maybe 10, 20 engineers responsible for this entire plant that makes 1 single product. (Participant 05, Student, CE)*

*Because robotics is basically a combination of all types of engineering. A lot of types of engineering I think. And a lot of the time the system that you are working on, is not going to be independent. Almost never, like you will never have something where other teams don't depend on you. (Participant 35, ECT, PE)*

The highly collaborative and interconnected nature of the CE and PE Industry necessitates that individuals not only have strong foundations in basic engineering principles to complete their job well, they must also be cognizant about underlying systems. This implies understanding how their own work affects the work of the people that they are working with and vice versa, and, moreover, how the system is part of a sociotechnical whole. This thus goes beyond mastery in a purely intra-personal sense as 'traditional' views on expertise have understood it to be one has to be aware of interconnections. The complexity of this interconnectedness understood and the responsibility it then takes to act in such a system was poignantly reflected in participant 49's (ET, PE) response:

*Let's say I design something, I can design anything I want. But, you must think about the next person [in charge of the process after you], how will they open it, and if they are able to do it successfully. These things are very important. You cannot think that I want to design this, I can 'anyhow' design, I can 'anyhow' cut it. But you must think if the other guy, if another person does it, are they able to do it? And also about the maintenance, if it becomes spoiled later on, how do we maintain it, you know what I mean? As an engineer, this is something very important. (Participant 49, ET, PE)*

Participant 49's (ET, PE) response highlights a deep awareness of how his work will affect the people he is working with, which reflects in his approach to work: actively considering whether his colleagues are able to replicate his actions and whether these will affect the maintenance of the product. What is also noteworthy about participant 49's (ET, PE) response is that he is not just aware that his work processes will significantly affect the work process of his colleagues, he also considers his colleagues' ability to execute a certain process and alters his design decisions based on that. In addition, he goes as far as to think about the maintenance of the product.

The fact that he is keenly aware of his colleagues' abilities and the different stages of product development reflects a certain conscientiousness and professionalism about his work ethic. Thus, this suggests that one's level of domain expertise is intimately connected to one's work ethic, otherwise known as the qualities of professionalism that they display. It is these qualities that our report will explore in the section below as the next dimension of intra-personal expertise.

### 3.1B Achieve professionalism at work

*“Besides skills and knowledge”, the teacher highlights, “your attitude is crucial. You need to have faith in yourself. A “you can do it” attitude is required, and you need a growth mindset”. He regularly comes back to these issues in the rest of the class at the pilot plant, and much of what he shares is directly related to the future vision of students becoming professionals. He also seems to want to instil a sense of seriousness that he wants the students to develop (Fieldnotes, Pilot Plant, 15 Oct 2019).*

The conventional view of expertise is skewed towards skills development and knowledge acquisition. This is too narrow for developing mastery in the digital age. Remarkably, rather than specific technical skills or knowledge, almost all of our interviewees instinctively point to either a certain type of work ethic or approach to work when enquired about the main characteristics of experienced and expert engineers. Apart from possessing deep basics and foundational skills, individuals that stand out in the CE and PE industries are those that strive to actively embody the norms of the industry as well as display professionalism at work.

#### **Professionalism is how we do the job (skills is what we use to do it)**

Skills and knowledge is what one uses to do a job; professionalism is *how* one does the job. In other words, professionalism is the conduct, behaviour and attitude of an individual at their workplace. Professionalism involves consistently achieving high standards, both visibly and "behind the scenes" – whatever your role or profession. For instance, during a field observation at *Box Builder*:

*We were surprised that technicians, despite the repetitiveness of their actions, put a lot of care and attention in producing and putting together. (Fieldnotes, Box Builder, 23 Dec 2020)*

Similarly, this strong sense of professionalism was also shared by participant 14 (MCT, CE), who gave the following response when asked what were the important characteristics that one must possess in order to succeed in the industry:

*Oh, characteristics, I would say, to be detail oriented. So, you need to ask yourself, when you encounter issues, to ask yourself, why. Why, why, why, why, why. So you got to ask yourself at least 5 times. So like, quoting the example of a pressure transmitter not working? So you ask yourself why the pressure transmitter is not working. Then, if you say, oh, because instrumentation is faulty, then why is instrumentation faulty? Then you may come out and say that, yeah, because certain equipment got spoiled. But why did the equipment get spoiled? Then you may say that, oh because the temperature is too hot, the equipment is not designed for it. So you got to keep asking yourself a lot of whys. And then, too, in order to find out what is the root cause. So the other, I think the other characteristic is that, you need to, be able to document very well, so, very often, problems repeat themselves, but in a appearing form, so it is a, very good characteristic to document things well, so that the, next time, some, shades of the old problem come out, then you have, some ready-made solutions for it. Then you don't have to re-invent the wheel also. And, of course, certain things are quite common, and you just have to work at it, and not give up, I would say. (Participant 14, MCT, CE)*

### Qualities that ensure quality and safety

Participant 14's (MCT, CE) response highlights two qualities in particular- the habit of being detail oriented and the habit of documenting things well. These qualities are just two of the many other qualities that our interviewees listed as being characteristic of outstanding employees. For instance, attributes such as the conviction to resolve issues rather than simply ignoring them out of convenience (Participant 05, ECT, CE), commitment to not cut corners (Participant 20, ET, CE) and the ability to think on their feet and solve problems effectively and efficiently when problems arise (Participant 07, ECT, CE).

Professionalism seems particularly important because upholding standards of professionalism ensures that safety regulations are met and the quality of machinery and products are not compromised. Participant 15 (MCT, CE) shared the following:

*For engineering, let's say you've a design error, something happens, some accident happens, it's a really tangible accident you see. So let's say a gas pipeline in my company for example, you design wrongly, then let's say it's in high pressure, what happens if somehow it just – the gas pipeline just suddenly bursts, what if somehow someone is standing there. And all of this is because you didn't design your pipeline properly. So we're talking a lot on safety, a lot on life and death. So there's really very little room for error. For engineering. (Participant 15, MCT, CE)*

Indeed, it is the level of professionalism that a technician displays in the industry that sets them apart. As participant 05 (ECT, CE) shares, senior engineers display a conviction to resolve things, to ensure that the plant is working, to follow all of the procedures, and standards that they have in place:

*Their conviction is one thing that, uh, I guess makes the difference. With that said, that sets us apart from them, and if we want to be at their level, we really need to have that sort of spiritual mindset, to, to adhere to all these, all these requirements. (Participant 05, ECT, CE)*

Standards of professionalism can be nurtured early by introducing them to students enrolled in engineering courses at tertiary institutions, even before students are first exposed to workplace settings. During one of our fieldwork sessions at Pilot Plant, we saw how instructors were actively trying to instil a particular set of skills in the students on top of factual engineering knowledge. Engineering students are increasingly required to learn how to spot patterns, solve problems, get acquainted with real world issues and develop an 'engineering thinking mindset':

*It becomes apparent to me during this part of the day that the teacher is trying to address another set of skills in the students. Rather than an emphasis on factual knowledge (although I have to say that everything is still communicated quite factually up till this point), students need to learn how to spot patterns, solve problems, get acquainted with real world issues. "You need to develop an engineering thinking mindset". (Fieldnotes, Pilot Plant, 15 Oct 2019)*

This mindset includes problem-based learning and developing critical thinking skills, something that was highlighted as contributing to becoming a professional. Participant 07 (ECT, CE), reflecting on his experience during his Polytechnic years, mentions instances where he encountered issues or problems:

*The practical might not go well. and our lecturers, my lecturers, are really cool. they will just come to us and say, ok, your experiment didn't go well, why didn't it go well. not all of them will spoon feed us the answers, they will actually ask us to think why didn't it go well. and we will actually sit and discuss, all right, there's a possibility that there was not*

*enough pressure, not enough fluid, the list goes on and on, and this contributes to your troubleshooting skills. (Participant 07, ECT, CE)*

It is evident that qualities of professionalism are highly valued in the engineering industry on top of domain skills and knowledge. Moreover, they can be introduced to engineering students even prior to entering the industry. As the majority of our interviewees pointed to professionalism as the defining characteristic of experienced and expert engineers, and to the role it plays in ensuring quality and safety, it highlights just how much of a key attribute it is for technical professionals to develop this aspect of mastery in the CE and PE industries.

### 3.1C Ignite and instil élan

*Another noticeable moment is that for quite a while nothing seems to happen (they must combine two liquids in tubes while maintaining a specific pH level), but at a sudden moment the numbers begin to spike and all the students gather around the monitor saying “Wow wow wow!”. It reminds me of the lab experiment last week and may point at the importance of the notion of ‘wonder’ within developing mastery; gaining respect for and finding pleasure in gaining knowledge on a specific area of interest. (Fieldnotes, Pilot Plant, 29 Oct 2019)*

Having identified earlier the different dimensions of intra-personal expertise, we proceeded to dig deeper by asking interviewees how one can go about developing these different dimensions of expertise. The responses suggest that while different dimensions of expertise can be modelled and learned, they cannot be taught explicitly. Instead, they were dependent on one’s own initiative and drive to actively develop, learn and improve. Furthermore individuals in the CE and PE industries who displayed these different dimensions of intra-personal expertise also tended to be those that exhibited higher levels of passion towards the field of engineering as compared to their peers.

Wonder, curiosity, passion, drive, motivation, and more. All these are key to developing mastery. They might seem diverse – even disparate – at first glance, but what runs through them is that interviewees did their jobs with élan – a vigorous spirit and enthusiasm manifested in a multitude of ways. We elaborate on these manifestations below.

#### Curiosity, tenacity and passion

The following was participant 05’s (ECT, CE) response when asked where one could pick up the ‘engineering mindset’ or if there were other ways that one could develop this mindset by themselves?

*No, in the technical field, you need a certain sense of curiosity. No one becomes technically sound simply by ideas coming to them. You have to, you have to be curious about how the world works. You have to desire, hunger for knowledge. (Participant 05, ECT, CE)*

Moreover, he highlighted – as did many other participants – that facing problems and aiming to solve them rather than looking away is a good indicator of one’s expertise in a field:

*My boss in my previous company, he was a true blue critical thinker. I, because, as a young person, I’m afraid whenever issues occur at my plant. Because I’m not able to, you know, I’m not able to contribute 100% due to my lack of experience back then. But for him, he loves problems, no matter what the problem is, he runs in, he runs to wherever it is. He says: ‘what’s the issue, tell me, what’s the issue, give me, give me. give me problems, give me problems’. You know? He’s got that, that really kid-like enthusiasm. Like a kid in a candy store, you know? (Participant 05, ECT, CE)*

Participant 05 (ECT, CE) suggests that his boss' competence comes from the deep interest and passion that he has in his job, such that he is always looking forward to solving new challenges that may emerge. While the example provided by him may be a light-hearted one, passion is undeniably an important factor in developing intra-personal expertise. His response highlights two things in particular: first, the relationship between the development of mastery and passion and, second, how passion is closely related to challenges and problem solving. As mentioned by others, passion is what enables an individual to persevere and press on when the going gets tough and when they face challenges at the workplace.

### **Proactive, undulated, and drive**

To expand on the former, one's growth and advancement in skill and expertise is, more often than not, related to their own drive and motivation in developing these skills. This is also mentioned by participant 20 (ET, CE):

*Basically when I learn about something and develop an interest towards it, even when I go back home, I will look through all these manuals. Previously there was no Google, right? So I will try to get all the manuals from somebody somehow somewhere. (Participant 20, ET, CE)*

Participant 20's (ET, CE) experience highlights how the pursuit of becoming better at one's job is often achieved through demonstrating proactiveness and expanding one's knowledge even outside of work hours.

Participant 32 (ECT, PE) illustrates this with an example where his company manufactured a product with a tight deadline and found himself constantly having to trial and error:

*Definitely, if you need a solution in 2 weeks, and you have nothing. Now that's definitely daunting but I think it's ok I think. Like we all love challenges here so we actually work towards it. (Participant 32, ECT, PE)*

He further adds that the high pressure nature of his job eventually got to some of his colleagues where they could not take it and they had to leave. Conversely, he also shares those who stay on are people that *"actually like the job, can do it, they can take the stress and then they will stay"*.

Accordingly, the drive and motivation of individuals influences the extent to which they actively seek to expand their own knowledge. While most of our interviewees have undergone on the job training, participant 20 (ET, CE) highlights that, while crucial, there are certain challenges to fully learn and understand equipment or processes at work. *"Because at work it's hard to kind of read and do the job. At work it's [mainly] [just] do[ing] the job."* This hints at two things: firstly, working and learning are often intertwined processes that happen in the course of work and, secondly, there's also a need to step back and reflect on what is learned. The often demanding context of manufacturing work may make the latter – learning less easily accessible.

Hence, Participant 20 (ET, CE) often brought home manuals to further read and study by himself. This same demanding context, however, can simultaneously cause one to be resilient when faced with setbacks and failures, thereby contributing to passion for the profession and staying in the industry for the long haul. Some of our interviewees shared that their industries are not the most glamorous, appreciated and recognised ones. Those that stay on and persevere in the industry are often those who are genuinely passionate about what they do.

### 3.1D Summary

To summarise, this section of the chapter has gone through the different aspects of intra-personal expertise, which is also the first dimension illustrating how mastery is distributed between people-people interactions.

As the name suggests, intra-personal expertise is primarily concerned with becoming proficient in one's own domain and job scope. In addition, intra-personal expertise also encompasses other factors such as professionalism and doing your job with a certain élan. While the latter may not always be conventionally emphasised and made mandatory in the attainment of the former, our findings have found that the latter and former are highly related to each other. Over and over again, our interviewees have pointed to the qualities of professionalism, élan (and its different manifestations such as curiosity, passion, motivation and drive) as being equally or even more important than being knowledgeable in one's domain. In other words, while formal education and knowledge in domain skills is a requirement to enter the professional field, in and of itself, it's not sufficient for becoming an expert.

Moving forward, the next section of the chapter will explore another dimension of how mastery is distributed between people-people interactions, this time not within a professional's self but between different professionals.

### 3.2. Develop inter-disciplinary expertise

Intra-personal expertise, which the previous section focused on, aligns with the 'traditional' view on expertise as outlined in the theoretical chapter of this report. It also expands on it as outlined in sections 3.1A to 3.1D. But our findings revealed that most of our respondents felt that more is needed to complete the whole piece for mastery:

*What I realise is that very very few people understand the whole piece because when you're an engineer, you have a very specific, they call it the vertical, you have a lot of depth of knowledge on and for certain roles you need to see how those different pieces fit together and that's not common, that's quite rare...So I only understood that after some time and that **gives you some confidence that you don't have to worry too much if you don't see everything at once because chances are not everybody does.** (Participant 07, ECT, CE)*

#### Stepping out of comfort zones to understand the whys of the whole piece

As the quote above shows, mastery is primarily perceived as developing deep domain expertise. However, the idea of having to "understand the whole piece" also hints at the fact that a true master needs to be able to go beyond his or her own domain. This was shared by participant 43 (ET, PE):

*If you don't upgrade yourself, you will probably be – some will move up to be technician, some move up to be supervisor, because they have all the experience, and at most maybe you will go to an engineer post. I mean, you will still grow with the company but you will almost – that's all you can do. But if you really want to be moving up, really, you know, do more in life, and if you are interested, then you have to keep on upgrading yourself. **Because just with the experience, the basic knowledge we have in machining, I don't think it will get you very far.** (Participant 43, ET, PE)*

A similar sentiment was reflected in our interview with participant 33 (ECT, PE). He shares how, as a product lead in his company, he is expected to coordinate efforts between all of the different departments:

*I might not be the best suited person to actually advise the different team members because I come from a different background, and I might not know a certain subject area very well. Yet I have to take the responsibility of asking my team members 'why are you doing this, why can't you do something else?' In doing so, I have to step out of that comfort zone in a sense as well. (Participant 33, ECT, PE)*

He shares how, as a product lead in his company, he is expected to coordinate efforts between all of the different departments: As a product lead he is expected to be well-informed of the matters not just in his area of training but in all the other areas as well.

While inter-disciplinary expertise is traditionally seen as something necessary for professionals at the top positions of the organisational hierarchy (e.g. reflected in the perception that these positions are for generalists), our findings highlight that this view is not as applicable to the changing nature of the CE and PE industries today. Indeed, as participant 43 (ET, PE) shared above, inter-disciplinary expertise is a highly acknowledged trait for technical professionals. With digital transformation and changing business conditions, inter-disciplinary expertise has become an increasingly important requisite for professionals of all positions and career progression stages to acquire. Henceforth, this section explains in greater detail what are the different components that make up inter-disciplinary expertise.

### 3.2A Traverse across disciplines

*Engineer S carries an old school exercise book. Beside him, lead engineer U is drawing and explains the next step he must look into. It involves the orientation of the robot, developing an algorithm that enables the robot to identify or recognise the depth and bumps on surfaces. She explains how he can work on the algorithm so they can test it out. Meanwhile, I notice how the engineer constantly moves between his PC and the floor; between coding and his physical tools. (Fieldnotes, Cub Cleaner, 4 Dec 2020)*

In the contemporary workplace, the system one works in usually crosses multiple disciplinary boundaries. Professionals working in the CE and PE industries need to be able to smoothly traverse across these disciplines in their day-to-day work and even actively look for it in order to master their profession. As an example, with digital transformation currently taking place, processes are becoming increasingly automated and data plays a more prevalent role than ever before. Data analytics and data science, specifically, have emerged as important skills, and this can be seen in the responses from our interviewees. Participant 41 (MCT, PE) shares:

*I think the expert engineer in the future will also need to understand how to do data science, how to digitalise certain processes as well. Because that is the trajectory that we are moving towards. The trajectory of the future. So expert engineers would need to incorporate both engineering knowhow and also how to use the data that we have available to us. Because I believe in the future we need to integrate both data science and engineering together. Because if you were to look at factory 4.0, factory of the future, a lot of these technologies will be automated, and a lot of investigations in fact will also be automated. So we cannot run away from the fact that it's going to change. So that's important for future engineers, to be exposed to and learn about digitalisation and data science. (Participant 41, MCT, PE)*

### Integrate different domains (not 'in-lieu-of' or 'added-on')

Indeed, as participant 41 (MCT, PE) puts it, engineers need to be able to integrate both engineering and data science in their work. Moreover, his quote also alludes to the nature of the relationship between one's disciplinary domain and other disciplines in the contemporary workplace. The importance of possessing deep domain foundations in the CE and PE

industries remains unchanged, and the use and understanding of data (as well as other emerging disciplines for that matter) cannot simply be 'added on' but must be integrated within the core domain. A corollary is this: even though digital transformation in the CE and PE industries has placed a huge emphasis on the importance of data analytics and data science, it is still necessary for engineers to possess deep domain foundations and the pursuit of interdisciplinary expertise should not come at the cost of neglecting the domain foundations of engineering.

This has implications for how to teach working professionals: rather than merely having to understand or know what an emerging discipline is (i.e. understand the technicalities of it), it is of greater importance to understand and learn how it operates and can be applied for one's specific work setting.

Participant 16 (MCT, CE), who is a data scientist reinforces this from the perspective of the emerging discipline:

*So one of the biggest buzz words now, which is AI and ML, right. Such a huge buzz word. So it doesn't matter if you are from computer science, you are from engineering, or whatever not. These engineers, when they go out into the workforce, they realise that we can't work without the ML information from computer science as well. We need artificial intelligence, we need machine learning. And then they start everything from scratch, python, they learn R, they learn about data science skill as well, because they realise that having an engineering, um, background, for, let's say I'm from the upstream business in, in my company, the upstream business deals with oil, um, oil uh, exacerbation for e.g. or in oil rigs, how we produce energy from oil. So, the technique is the same. right, but the data science behind it will change every single day. for e.g. how do we ensure that the oil wells do not have any fault in them, so one of the, one of the, in this case I'm working on in the upstream business is the, um, quality of oil, the darkness of oil that we use using IoT, internet of things, um and also sensors. so we take sensors from the underground, and then we are able to detect the dampness and quality of the oil, based on the soil quality. and that's data. **That's something you don't learn in university, about AI or ML, machine learning. but that's something being put into place, even if it doesn't matter whether an engineer, you are a data scientist, whatever not, when you come into the company, you realise, hey, everyone needs to play a part, everyone needs to bring in their game into this, so yeah.** (Participant 16, MCT, CE)*

As a data scientist, participant 16's (MCT, CE) quote shows that it is not just engineers who need to expand beyond their engineering skill sets and traverse across different disciplines smoothly: data scientists are also expected to be aware of engineering techniques and processes as well. In other words, integration is key, regardless of one's starting domain. Both responses show that inter-disciplinary expertise (where different disciplines are truly integrated) is relevant for individuals working in the CE and PE industries, regardless of their background and profession.

The responses also expose a common misperception about the value of data science. With the growing prevalence of data science in the industries, the spotlight is often on how engineers can no longer just rely on their engineering knowledge they gained at school. However data or data science outside of an engineering context may only be of limited value, and by extension, have limited contribution to one's professional expertise. Data science is only valuable when integrated with the engineering knowledge developed in school. That engineers can no longer rely on what they learned in school is thus the wrong lesson; the right lesson is that they must rely even more on the engineering knowledge that they gained in school for data science to even begin to have value to them (which affirms the importance of deepening domain fundamentals explained in section 3.1).

### Moving comfortably and smoothly

Integrating different disciplines well makes it possible for one to move comfortably and smoothly across them. Here, participant 17 (ET, CE), an experienced professional who has just left the CE Industry, provides an example of traversing smoothly across different disciplines in one's day to day work:

*So mastery in a field like mine, chemical treatment, not only understands a particular part of the process, but would understand the intricacies between all of them. Because there are a lot of other factors involved in what happens in one process that come from another. **I need to understand very well all the processes, so I know, um, what things might be involved when I need to solve a problem. Ok. At the same time, I know very well what my chemistry is and what is available, ok. Like, because we have a lot of different products, a lot of different applications that could be used. I need to understand what is best for us to use for a particular case. Correct? And keep myself updated with the newest technology that we have (...)** So mastery is knowing the process very well, knowing your products very well, ok, your technologies very well, and communicating that in a very very, I feel that you can be very technical but not necessarily know how to communicate that knowledge to other people, and this is very important with your customers because once again, your customer, my customer, they have very little knowledge about chemistry. They don't have to focus on that part, they pay us for that, all right, but they want to know what you are doing with their system, so when you are going to put something there, you have to have this very good skill to explain what is behind it and the reason, the reasoning behind it. (Participant 17, ET, CE)*

Participant 17 (ET, CE) details how a master in his field is someone who is very strong and familiar in their chemistry knowledge and is well-versed in the different processes of the chemical treatment, which is indicative of possessing deep domain fundamentals. In addition, a master is also well-informed of the newest technology and knows which technology is the most appropriate and compatible for a certain process. Lastly, his view of mastery requires a good understanding of the business context, which includes product knowledge and knowing how to sell and communicate technical knowledge to customers in a way that is easy to understand. Indeed, the example shows that mastery involves not only a good grasp of the different disciplines and skills (from domain fundamentals to digital skills to being a good salesperson) but one must be able to move between the different disciplines smoothly and comfortably as and when the situation requires.

### Increasingly expected, required, and respected (and the risks for anyone without it)

Apart from the digital transformation of the CE and PE industries, companies are looking at becoming progressively leaner in their daily operations. This has necessitated employees to train across various disciplines so that they are able to handle different tasks that are assigned to them. Participant 33 (ECT, PE) shared how a lean process requires their workers to be knowledgeable in a broader sense:

*The turnover period of manufacturing a product is deliberately kept very short, within two weeks to a month, if possible, So the advantage of our company is that because all of us are very adaptable, in a sense, and whenever we hire for a specific role, we need a team such that when we want to handle just proof of concepts, this guy must know – doesn't have to specialise in a certain thing, but he needs to know a bit of everything, such that when he's working on it, he doesn't disturb everybody in work. For example, if I'm someone who is supposed to do, let's say a wireless charger for example, I don't know software. I don't know how to code, then maybe I must disturb another team lead from another software department. I must disturb the team lead from the power systems department. I must disturb the team lead from the mechanical department. If you're disturbing everybody then you're, you're spending, you're not spending your time executing, you're spending the time actually just trying to understand whether or not your work is actually viable. (Participant 33, ECT, PE)*

From the example it is evident that having knowledge of the different disciplines is a requisite that is expected of employees due to the fast paced environment of their workplace. What is noteworthy is that lacking knowledge in other disciplines is being regarded as a major hindrance to productivity levels as this would lead to valuable time lost to execute one's work.

In the same vein, participant 33's (ECT, PE) colleague, participant 52 (ET, PE) also shares about the importance of employees being able to traverse across disciplines smoothly in their company:

*Our company is not a big organisation with many sub functions and so on. So a lot of things are actually, resources are very lean. We never train 1 person to do just 1 job. We call it cross-training, multiple jobs and so on. Everybody should know a few sub assembly processes and so on. That's how we cater for all these unforeseen circumstances, go for mc, go for leave. So we still have people who are able to manage. Cross training is important, it is not enough to have 1 person to do that job, or [even] if that is an easy job [to them], you are wrong, you make sure you have a backup. So all this training is very important. (Participant 52, ET, PE)*

Participant 52 (ET, PE) shares how his company is intentional about ensuring their employees are cross-trained so that their work processes are not affected even when someone is not there. In particular, his statement that 'it is not enough to have one person able to do the job' reiterates our earlier point that possessing domain expertise is no longer sufficient. Indeed, being an expert in the traditional sense of the word may become a hindrance when a company is striving for innovation. Therefore both participants 33 (ECT, PE) and 52's (ET, PE) quotes highlight how being able to traverse across disciplines smoothly is important in their company such that it is almost mandatory for all their employees to be cross-trained.

Lastly, beyond recent trends related to the digital transformation of the CE and PE industries and of companies 'going lean', being able to traverse across disciplines has always been a crucial albeit understated skill because of the many different functions and roles within organisations. More often than not, individuals working in the CE and PE industries, especially those whose work is more project-based, must communicate and work with individuals not belonging to the same department or profession as them or even those from outside of their organisation. Over and over again, our interviewees shared with us their different experiences working with "all different types of people" whose backgrounds differed significantly from them.

Participant 15 (MCT, CE) reflects on his following experience during the early stages of his time at the company:

*When I joined this company, for the first 3 months, I was really clueless about everything. Because whatever I learnt just in university, I had to revisit them. That's for sure. But at the same time there's so many things I'm not sure about. Because I'm from a mechanical background, I do not know much about civil [engineering]. I do not know about all the different types of materials they use for cement. All the different kinds of foundation that they use. All the different kinds of, for example, metal grating they will use. All these are not in my knowledge in mechanical. All these I had to pick up on the job. And a lot of times, it's really whether you're really humble enough to tell people that, sorry, I have really no clue about this. Can you please teach me? This includes the vendor. You've to tell them, can you please teach me and tell me what all of these are, then I can decide whether they are really good. So there's a risk in doing this of course. Because sometimes the vendor might try to – what we call, try to eat you. So they will tell you, oh, this is very good, that's very good. But because you're not very technically knowledgeable in all these stuff, then you think, oh this is really good. But in actual fact, they're not really good. So, that's where you have to be a bit wiser. (Participant 15, MCT, CE)*

Here, participant 15 (MCT, CE) shares how his lack of knowledge about other areas outside of his background had placed him in a vulnerable position where the vendors would “try to eat him” and take advantage of his lack of knowledge. Arguably, with the rapid pace of digitalisation it will become increasingly harder to stay up to date about developments within and outside of one’s domain, making the issue of inter-disciplinary expertise even more prevalent.

In contrast, participant 07 (ECT, CE) shares the following:

*But, uh, we do, we are also trained to utilise the technology [that the operators use] as well, even as an engineer, because sometimes we need to try a certain troubleshooting method or we want to just experiment to see what can happen, it's always good to know um how these things work. I, I always tell my, my juniors or my colleagues, if you want people to, if you are doing a job and you want people to respect you for it, you have to make sure you can do some part of their job, so that they know when they talk to you, you know what, you know what they mean. (Participant 07, ECT, CE)*

The quote highlights how the ability to traverse across different disciplines smoothly, especially the discipline with which the person you are working with is specialised in, is crucial in gaining their respect and stands to benefit the overall working one’s relationship.

Being able to traverse disciplines smoothly expands exposure to different kinds of domain expertise, thereby growing one’s own mastery in the process. This relies on more than technical knowledge but it is shaped by social connections and interactions (e.g. being taken advantage of or showing respect). Therefore, a precondition for developing inter-disciplinary expertise is to have an open mindset and be genuinely interested in how other professions tackle certain issues. In other words, one must not have any biases.

### 3.2B Overcome disciplinary bias

*I’m looking at technician F struggling to put this part of the Box together. Much like how someone would set up IKEA furniture without first reading the instructions. That process earns him close supervision from the engineer who is staring at him doing the job. It’s interesting because it feels like when you’re not doing a great job you get supervision, but this builds up the stress. Surprisingly, technician F does not go to the engineer for help now he needs help with something. Rather, he finds it from his colleague, the senior technician who is sitting beside him (Fieldnotes, Box Builder, 10 Dec 2020).*

As seen in the observation above, individuals may have a preference for who they reach out to. More often than not, they prefer to seek help from someone like them. In the workplace, this is often from someone in the same discipline as them. But our research findings show that this also includes those with the same qualifications/backgrounds, and the nature of the bias that needs to be overcome is similar whether this is between disciplines, qualifications, and backgrounds. The observation at *Box Builder* above allows us to expand our understanding of this type of bias, and in doing so expand our ability to tackle it subsequently.

While our report has already established the importance of being able to traverse across disciplines smoothly, one does not develop inter-disciplinary expertise instinctively. Unlike the mandatory cross-training as discussed by an interview in the previous section, this is not always easy for larger companies that have more sub-functions and different people specialised in their specific areas. In such instances, it is harder to ensure or promote cross-training amongst employees. In order to untangle this in greater detail, this section explores some issues reported by respondents about acquiring inter-disciplinary skills and how these

pertain to the presence of disciplinary and professional silos where there are limited opportunities for individuals from different disciplines and professions to interact and share their knowledge with each other.

### Being interested and willing (and when experience can hinder instead of help)

Acquiring inter-disciplinary expertise begins by appreciating the diversity of disciplines in the industry and being actively aware of possible biases. In our findings there are instances where such inter-disciplinary bias was present between, for example, engineers and data scientists:

*In the wider team. I think maybe about 4-5 [engineers] would be more inclined in the data science aspect of it. So that gives you a real representation of how many engineers are actually more inclined to data science. Very few, very few. Because to be honest, when you talk to data scientists and they get very technical, they talk about things like python and coding and all that. So we engineers will totally switch off. Like it's not my field, I will switch off. So, for me, because of my PhD background, I appreciate coding, and what it can do for us. To be honest, it's difficult for me to motivate my team, eh guys, I think you should look at data science. It's not their field. So how are we going to make people more interested in data science? (Participant 41, MCT, PE)*

Participant 41's (MCT, PE) example shows inter-disciplinary bias being played out between engineers and data scientists. When interacting with the engineers, data scientists would use highly technical and specialised terms that others outside their discipline were unable to understand. On the other hand, the engineers themselves seemed uninterested and unwilling to learn about data science. In other words, inter-disciplinary bias failed to let both parties traverse between different domains. As mentioned in the section on how being an expert in the traditional sense of the word may become a hindrance when a company is striving for innovation, participant 21's (ET, CE) examples listed below shows how being an expert or being too invested in one's own discipline may discourage one from learning about other disciplines:

*I worked with a lot of people with lots and lots of experience but they can't separate their experience from the, to apply the digital domain. They just want to talk about the 30 years of experience they have about everything and we can't see how that would fit into this technical digital world. I think you need to have domain knowledge but also you need to have the right type of understanding of digital technology so you can have that conversation. (Participant 21, ET, CE)*

While the difference between a technical engineer and a data scientist may be obvious and can even be understood as a clash between radically different ways of working, closer to home we observed many more nuanced instances of such bias. Beyond inter-disciplinary bias, there may also be similar biases and silos *within* a shared discipline, between those with different qualifications, in particular, the tension between engineers and technicians. Participant 07 (ECT, CE), an operations engineer, alludes to this by drawing on the well-repeated analogy of engineers being the 'brains' whilst technicians and operators are the 'hands':

*I'm saying this from an engineer's perspective. um. from, from an operator or technician's perspective, they are on the ground all the time. so, eventually from point a to point b, becomes a part of their core. so this is part of their experience. but for engineers like us, we are not always on the ground, we are always in the control centre, we are thinking. So uh, there's 1 thing my colleague told me that's very interesting, he said, they don't employ you for your physical prowess as an engineer. they employ you for your brain. so, operators, the technicians, they are there for the valve turning. They are there to start up the plants. but, when there's a hiccup, that's when you come in. so that's why you can have maybe 50 different operators, but maybe 3 engineers. because they just want your brain power, and that was the first time in my profession where I heard something that spoke to me. That said, yeah, you, it makes sense. because I*

*don't always have to do the routine jobs that the operators do, like taking samples, opening valves. I don't do that. it's not in my requirement to do that. but, what is in my requirement is to resolve plant issues. it says there in black and white, I have to resolve plant issues. so that's my brain essentially. (Participant 07, ECT, CE)*

At first glance, this seems like a simple analogy distinguishing the roles of engineers and technicians. However, when examined further, it hints at hierarchical differences between engineers and technicians, with engineers being the “brains” regarded as more knowledgeable and competent compared to their technician counterparts who ‘only’ need to do manual and routine work. From the perception of a technician, this hierarchical difference was also recognized. Participant 11 (ECT, CE), brings up this dynamic and, moreover, also suggests that this creates unnecessary disciplinary boundaries restricting the development of expertise:

*But usually these engineers come in, but not stereotyping la, but I've come across most of them like, [they] usually have this ego whereby “you are a technician, I'm an engineer. I know more than you, you should listen to me”. But sometimes it's the other way round. Yeah so for me between this technician and engineer thing, there shouldn't be a gap whereby the engineers always feel like I'm superior to you. The engineers must [also realise that] sometimes the technicians know more than [them] because the technicians are out there more. Practically engineers are there only when technicians can't solve the issue. (Participant 11, ECT, CE)*

Participant 11's (ECT, CE) quote reveals how participant 07's (ECT, CE) analogy of engineers being the ‘brains’ and technicians being the ‘hands’ can play out quite negatively in reality. It highlights a case where both engineers and technicians are defensive and unwilling to consider the other party's opinion. This occurs because the engineers may see themselves as being more well-trained and theoretically sound compared to the technicians. At the same time, technicians may feel that they are being looked down upon, when in actuality they may be more familiar with the plant given that they spend disproportionately more time in the plant compared to the engineers.

Evidently, inter-disciplinary bias is present within the CE and PE industries, hindering the pursuit of inter-disciplinary experience. Hence, it is crucial to eliminate these biases and educate individuals in the industries about the importance of being aware of the diversity of disciplines and the need to learn from individuals in other disciplines.

#### **“I don't know” versus “I know”**

Fortunately, most of our interviewees brought up that they are aware of the fact that the people they work with come from a wide range of backgrounds and expertise. The contemporary workplace, for many technical professionals, includes meeting the experts in different domains. Hence, they highlighted that mastery, firstly, requires one to be aware of what you do *not* know and, secondly, how this requires the need to be humble, open and teachable when working with people whose background is different. This can be seen in the two responses below:

*Whether it is machinery, whether it is instrumentation, we are dealing with so many different types of people right. They are of different backgrounds. And they are of different expertise. And the thing is, most importantly, when you go into your job, you must be open to your surroundings, you know, open to what people have to say. Don't think that wah you know, you study until damn high, you think you know all your 'shit', but actually, sorry man, you go into the working world, it's an entirely different story. (Participant 09, MCT, CE)*

*All these I had to pick up on the job. And a lot of times, it's really whether you're really humble enough to tell people that, sorry, I have really no clue about this. Can you please teach me? This includes the vendor. You've got to tell them, can you please teach me and tell me what are all of these. (Participant 15, MCT, CE)*

Their responses reveal an interesting relationship between the *modus operandi* for inter-disciplinary expertise and intra-disciplinary expertise. Intra-disciplinary aspires to a point where a technical professional can confidently say “I know”. Contrast that to inter-disciplinary where the technical professional can confidently say “I don’t know” instead. Being able to build that humility and capacity to hold these seemingly contrasting *modi operandi* might turn out to be the defining skill to nurture in technical professionals for the future.

### **Being proactive to overcome barriers of disciplinary boundaries and lack of exposure**

Some of our interviewees were open and ready to learn from individuals of other disciplines and professions. They also hinted at the importance of seeking such learning challenges actively and independently. There are two main difficulties related to this: rigid disciplinary boundaries that are hard to traverse and a lack of exposure to individuals from other disciplines and professions.

To reiterate an earlier example from section 3.2A, participant 15 (MCT, CE) recalls how he was overwhelmed by the learning curve he faced when joining the CE industry. He was expected to pick up knowledge outside of the training he received in university, forcing him to approach the vendors he worked with to ask them if they could teach him the things he needed to know. However, not all of the vendors were open enough to share their knowledge with him and some even took advantage of his lack of knowledge to “eat him”. This experience highlights how even if one may be aware of the diversity of disciplines involved in the industry and actively takes steps to pick up such inter-disciplinary knowledge, the process of learning more about other disciplines is difficult and uncertain.

Participant 16 (MCT, CE) industry shares similar sentiments about the difficulty of learning beyond one’s discipline and profession. As a data scientist, his workplace is the office – detached from the actual site itself – but his job requires him to analyse site data. To better understand the data, participant 16 (MCT, CE) needs to actively approach people working in the different departments in the company to better understand the process behind the data. However, finding the correct people from the respective disciplines to learn from has been a challenging experience for him as well. He remarks:

*Like I said, my company has hundreds of thousands of employees all around the world. And, eh, and when you are working with a company like this, it's really easy to get lost. it's really easy to not get heard. You are just one speck of dust. well, I mean, among the whole pool. (Participant 16, MCT, CE)*

Both examples highlight the process of getting to know people working in other disciplines and professions and approaching them to learn more about their discipline and background is difficult for individuals to navigate by themselves. Hence proper structures and programs set in place by the company would be helpful, and we will elaborate on these in the next section.

In summary, this section has shown how the presence of inter-disciplinary bias in the CE and PE industries can hinder the pursuit of inter-disciplinary expertise. Even when individuals are aware of the diversity of the disciplines and actively try to learn from other disciplines, there are not always opportunities readily available for individuals from different disciplines to mutually learn and share their knowledge with each other. Hence, there must be solutions and initiatives to promote mutual sharing and exchanging of ideas and knowledge that take place beyond the individual level to enable individuals working in the CE and PE industries to

overcome disciplinary bias. This will be covered in the next section of our report where we will explore how safe intersectional spaces are crucial in enabling the mutual exchange of ideas and knowledge that can promote pursuit of inter-disciplinary expertise.

### 3.2C Foster intersectional rapport

*There is a sense of openness in the office, with lead engineer U as the firm but approachable team leader that provides guidance for the team. It is okay to ask questions or admit that you are unsure of what needs to be done, kind of like how a student interacts with the professor. There is no competition between the team members either, everyone has their own roles and works together to help one another. (Fieldnotes, Box Builder, 4 Dec 2020).*

This section looks at some ways in which our participants have overcome the difficulties described in the section above and explores how the notion of *safe intersectional spaces* - like the one described in the fieldnote above - can promote mutual sharing of knowledge amongst different disciplines, ultimately enabling individuals to develop inter-disciplinary expertise.

From our findings, we identified programs deliberately organised by respective companies for employees from different departments and disciplines to learn from and work with each other. This can be seen in participant 30's (ECT, PE) orientation program experience which we share in some detail below:

*For my company, I guess – or for most companies also, there would be an orientation. So for let's say a manufacturing company you would need to understand the product. **So for us even as engineers, we would actually be required to learn from the senior operators or the technicians. so they were my first teachers when I joined the company.** So we created the product from start to finish and we were attached to them for 1 month. They were technicians. But they have been with the company since day 1. So they are well versed in the product that they're making because day in and day out they are doing the same thing. They're doing routine jobs. So we are attached to them and we go through the training with them, then they actually – sometimes they would give feedback to us on what can be improved. And that's where we gather insights and then plan with other engineers to see how we can improve the product or how we can improve the process. **So I will be going through from the start of the product and from the first process right to the last process. So we have, just imagine, we have 10 technicians. So from number 1 to number 10. Number 1 will actually be just focused on the first process. Then whatever that number 1 does, he doesn't know what the next process of what number 3 does. So, during my orientation, I completed the whole process, from 1 to 10, every day I will spend 1 to 2 hours with them before I focus on other stuff.** (Participant 30, ECT, PE)*

The orientation program at participant 30's (ECT, PE) company is a keen example of removing intra-disciplinary bias pertaining to engineers and technicians. Even though participant 30 (ECT, PE) is an engineer, his orientation program begins with being attached to the senior operators and technicians in the company, who he also sees as his “first teachers” in the company. During the orientation, these senior operators and technicians, who are extremely well-versed with the equipment, will provide participant 30 (ECT, PE) with feedback on what they think needs to be improved on and participant 30 (ECT, PE) will similarly take note of their different insights and reflect on what could be improved on or what could be changed. The structure of this program reflects how his company recognises the importance of having their new engineers learn from the operators and technicians so that the engineers will have a clear understanding of the operators' and technicians work processes and for the operators and technicians to get to know the new engineers better as well.

### Break down walls to break down biases

The value of having such a program is that it breaks down the “invisible wall between engineers and technicians” which participant 30 (ECT, PE) and our other interviewees, participant 11 (MCT, CE) and participant 07 (ECT, CE) have alluded to in their interviews. Without such a program, there may not be as many opportunities for engineers, especially those who have just graduated and joined the company, to interact with the ground technicians and observe them at work given that engineers are working in their offices most of the time. As participant 30 (ECT, PE) shares, engineers who work in the office and do not spend much time in the field, may lack a proper understanding of the different processes and products. This leads to them being unable to effectively address the situation at hand. Likewise, this is of equal if not greater importance for CE engineers working primarily in the office as they manage safety critical processes. A program similar to that of participant 30’s (ECT, PE) orientation helps to socialise both the newly hired engineers and the senior operators and technicians (something we will discuss in greater detail in section 3.3). Younger engineers may be intimidated by senior operators and technicians and the latter may occasionally feel defensive and threatened when younger engineers offer their opinion. Hence, a program like participant 30’s (ECT, PE) orientation can help to eliminate these sorts of biases and preconceived notions from taking root and fostering better communication amongst both groups instead:

*Because I've a lot of friends from different engineering industries, and what I gather from most of my friends is **they don't really spend much time with the ground technicians to really understand the pain or understand the products and stuff. Because as engineers, we are mostly in the office, and then we try to assume what was the problem or what can be improved. But we're not really addressing what needs to be done, so I guess – I would say there are some stories I heard where my friend who just joined a company and then when he joined there were actually senior technicians who had been in the company for 10-20 years. So as a fresh grad, when you enter the company and you try to give your opinion or input and then the senior technician will actually try to tell you off. They say I've been here for 20 years and this is how we do it. Don't tell me how to do my job. So, I guess as a fresh grad engineer, you'll be quite intimidated with that kind of attitude. Like that's 1 of the key things that – I mean somehow an invisible wall between engineers and technicians. I think it shouldn't be this way, if we want to improve the workplace or the communication we should collaborate with each other and we shouldn't have this mindset where oh just because you're an engineer, you earn much more than me, I don't have to tell you anything. We should actually talk to each other and help each other see how we can make it better.** (Participant 30, ECT, PE)*

### Socialisation, communication and collaboration

Apart from equipping the newly hired engineers with the knowledge of the various work processes, what is also noteworthy about the program is the socialisation aspect. As the quote below illustrates, overcoming disciplinary bias does not only involve learning about another discipline outside of one’s background and profession. For mutual sharing of expertise to take place, there must be a conducive environment for people from different disciplines to come together and to get to know each other. This necessitates the presence of safe intersectional spaces.

These spaces are meant to encourage people to become more open-minded and less resistant towards learning from each other. As discussed earlier, one pertinent factor preventing newly hired engineers from learning from senior operators technicians is the fact they were easily intimidated by them. On the other hand, the more experienced operators and technicians may not always be willing to teach, much less learn from other individuals from different disciplines when they have become so comfortable in their own area of expertise. Hence, participant 30 (ECT, PE) also shares how the value of the orientation program at his

company lies in how it promotes the building of rapport between the engineers and technicians and to establish a friendly presence among them, where sharing and learning from each other is seen as something mutually beneficial for both groups. Lastly, he mentions that another rationale behind the orientation program at his company is to introduce each engineer to the entire team of technicians and operators so that they can get to know each other at an individual level. This is to allow technicians and operators to get to know the engineers better and to foster a better working relationship amongst them as the engineers are expected to be working closely with them and to contribute ideas to engineers during their time at the company:

***I think it's more of building rapport with them and to actually establish a friendly presence that as engineers we are not really there to find faults with them or give them trouble. But we're there to support them because they're the operators or staff that creates our products. And we as engineers want to make it better or make their lives easier. I would say I have quite a good relation with my – some of the most senior technicians. I mean, respect goes both ways. I respect them because they have a lot of extensive experience. And they give their respect to me as an engineer because they know that I can get things done when they request something. Yeah it's the same for them. I guess my GM [General Manager], he created this program that all engineers have to go through the same program to start at the very lowest level together with the technicians to really understand the product before you go out and do your job. So it's more of introducing to the operators that ok we hired a new engineer. So this is so-and-so, what he's going to be doing in the next few years and how the technicians can contribute ideas to him. (Participant 30, ECT, PE)***

The example highlights how the process of learning beyond one's discipline and overcoming inter-disciplinary bias involves more than learning about the technical knowledge of other disciplines. It relies significantly on the existing working relationship and rapport amongst people from the different disciplines. With mastery becoming distributed in a digital workforce, this may also explain why almost every single interviewee mentioned 'communication' and 'collaboration' as one of the most important skills technical professionals would need in the future. This is touched upon in participant 41 (MCT, PE) sharing of the training program at his company where he mentions how rapport is an extremely crucial factor in the relationship between a trainer and a trainee:

***When we first entered the company, we [my batchmates and I] spent about 3-6 months in rotation in different departments in the UK. So they do go through the same level of training. But I think most importantly, in the UK, it's about meeting people. It's about recognising faces. They can recognise you as well. So I think that's a huge benefit... I think it's human nature. Imagine if you've not seen that person before and you sent an email requesting information. These people are very busy. They won't entertain. But if you meet them physically and they know [who you are] and you email them, they straight away reply because they know you personally. (Participant 41, MCT, PE)***

### **Working together to develop deep teaching and learning relationships**

The above examples underscore the importance of rapport during the process of teaching and learning. This is because teaching and learning from each other is not a one-off activity but an ongoing process. A solid working relationship is one that will encourage individuals to continue to share and learn from each other voluntarily on a continual basis even when they are not being forced to do so outside of the programs that the companies organise. Moreover, this highlights the interlinkages between domain knowledge and inter-disciplinary expertise: seeing the links within the system and acting on it is possible on the basis of understanding the system deeply from within your domain which, in turn, requires knowing the social elements that make up these linkages and relationships.

Rapport is not something that can be fostered immediately but takes time to develop. For effective mutual sharing of expertise knowledge to take place, it is advantageous to set up opportunities where both parties can interact and work together for a significant period of time so that they can fully understand each other's work processes. It also indicates the importance of workplace-based learning, and that what people learn at work is not just about technical knowledge and domain-specific skills but also about developing relationships and dealing with 'real-world' issues:

*So the benefit of me [being able] to sit down in their team physically is that I get to ask questions, I get to be part of their discussions. That itself, I think that is 80% of the training. To be involved in their day to day discussions. That's where you learn the most. (Participant 41, MCT, PE).*

Evidently, it is the time spent working alongside people from another discipline and being involved in their day-to-day work where one is able to learn and understand the most about another discipline. This was also mentioned by participant 42 (MCT, PE):

*The best way is to really work on a project with someone who is doing that, and then this is something we're doing here. So like six months ago, half of the mechanical team worked very, very closely with power systems, and they learned how they were doing the whole wiring, how they were choosing connectors. So now it has reached a point where at least three of them are super comfortable with doing it so they know exactly what needs to be done. so they don't even have to bother the power team to do basic prototyping, so we can just leave them to themselves. So it's really the best way, it's to work with someone who is doing that on one product and the best way to learn is by doing it. (Participant 42, MCT, PE)*

To reiterate our findings from this section, our report has identified the different factors that can help in overcoming inter-disciplinary bias in the CE and PE industries. Given the combination of factors required in order to prevent bias, we find that it is appropriate to think of them altogether as intersectional spaces. Firstly, given the difficulties and inconsistencies of relying on individual networking to pick up knowledge beyond one's discipline, there should be organisational measures in place to bring people of different disciplines together to enable mutual sharing of expertise and knowledge. Secondly, it is equally important that there are opportunities for individuals from different disciplines and professions to build relationships and get to know each other better. Having good rapport can help individuals in being more open-minded and receptive towards learning from people of different disciplines and professions. Lastly, mutual sharing of expertise and knowledge is not a one-off activity but an ongoing process, hence there should ideally be sufficient opportunities for individuals, especially those who are new to the industry and profession to work alongside people from different departments and to take part in their day-to-day discussions over a substantial period of time to ensure that one truly learns and understands the different features of their job and is eventually able to do it.

### 3.2D Summary

Overall, section 3.2 started by asserting that in the digital age, mastery has expanded beyond intra-personal expertise and individuals working in the CE and PE industries are expected to develop inter-disciplinary expertise no matter their position or career stage.

Inter-disciplinary expertise is the ability to traverse across disciplines smoothly in one's day-to-day work. While inter-disciplinary expertise may be highly valued in the industry today, there is not always a conducive environment for one to develop it given the lack of opportunities to learn from individuals in other departments, disciplines and professions. While some of our interviewees have attempted to develop inter-disciplinary expertise via personal networking,

the outcomes have not always been fruitful. Moreover, the process of learning from people in other backgrounds, disciplines and professions is made even harder when there are already pre-existing biases and tensions between the different groups, one notable example being the problematic dynamic between engineers and technicians. Therefore, our findings show a need for intersectional spaces to help remove any potential or existing barriers and biases that prevent individuals in different departments and professions from mutually learning and sharing with one another.

Our findings also illuminate how inter-disciplinary expertise in the CE and PE industries is not just about being equipped with the most “In-Demand Skills” or the most number of technical skills across the different disciplines. Instead, a critical element of inter-disciplinary expertise lies in its social aspect. This implies being open-minded and receptive towards learning and sharing with people from different disciplines and professions. Equally important is building rapport and spending time with people over a substantial period of time to ensure that one truly understands what other disciplines and professions entail. This goes back to what the report mentioned in the beginning of section 3, that despite the prevalence of digital devices and technology in the industries and the enormous emphasis of digitalisation in companies and policies, interactions at work and the way in which people become an expert in certain professions remains first and foremost in the interactions between individuals.

### 3.3. **Learning through multi-generational expertise and people of different hierarchies and seniority**

#### **Why developing mastery in the digital age involves acquiring inter-generational expertise**

Our previous section covered how mastery in the digital age is distributed between people of different disciplines and even within shared disciplines. This section proceeds to explore how mastery is also distributed between people of different generations, seniority and hierarchies and shows why they are important to acquire in developing mastery. It should be mentioned here that our use of the term “inter-generational” is more all-encompassing than merely referring to those belonging to different age groups. As we will show, apart from being distributed between professionals of different age groups, mastery is also distributed between individuals of different seniority and hierarchies, who have expertise in different generations of technologies, processes, and systems.

Digital transformation in the CE and PE industries has placed a huge emphasis on the use of technology and digital devices. Hence, skills such as data science and data analytics are now perceived as the most applicable and relevant types of skills. On the other hand, the skills and expertise of the older generation, often more manual and traditional in nature, are often popularly portrayed as ripe for disruption given that with the automation of processes, engineers and technicians no longer need to perform such types of manual labour compared to the past. However, our findings show that mastery does not only involve pursuing the latest technology and skills. Instead, as the report will explore further in section 4, digitalisation and the increasing automation of processes has obscured the importance of the skills and expertise of an older generation. Even though the importance of the skills and expertise of the older generation may not be readily seen, they remain extremely valuable because they enhance one’s troubleshooting skills and give them a more holistic view of the system. This can be seen in participant 43’s (ET, PE) response below:

*But they [younger generation] don’t know where these tools come from. In case anything goes wrong with the tool, they actually don’t know how to do a lot of the troubleshooting. But for us, because we know how the tool was being made, the geometry that affects*

*the machining, this and that, so when things go wrong, we have the opportunity or luxury because we're being trained, we have the knowledge to understand that. So, when it comes to some of the troubleshooting we're doing ourselves, it becomes more handy to do. So, we have the additional knowledge compared to today, these people are being trained. (Participant 43, ET, PE)*

Conversely, just as it is important for the younger generation of professionals to pick up the skills and expertise of the older generation, the older generation must be willing to embrace technology and be comfortable with using digital tools and technology. However, complicating factors here are people potentially being resistant to or uncomfortable with the use of technology:

***Because unfortunately there are some SME so called the bosses themselves they are not so open [to technology]. Because they're so used to the way it's been run. And they can't see the immediate benefit with technology. To do it. So again, when I worked for this SME company, when I was trying to build the new plant and trying to put in some technology inside there, with some advanced things to do, because it's almost alien to most of the people there. And if you ask the engineering group of people, they say, hey, why not you go look at this? Nobody wants to do anything. Because they're so comfortable with whatever they have. That's the first reason. Because they've been there for 10-15 years. They've been doing the day in day out, like what earlier I mentioned, the cow path, so comfortable moving. Suddenly you ask them to change direction, they're lost. They say, sure or not? This one high risk low volume, maybe doesn't work. This one, woah. They will give you a lot of reasons why you should not be doing that. Because they're not in their comfort zone. (Participant 43, ET, PE)***

The quote above shows how some of the older generation of professionals in the CE and PE industries are uncomfortable and resistant towards digital transformation because they are used to their own way of doing things. As participant 43 (ET, PE) puts it, they would rather stick to the present way of doing things than be open towards working with technology. Moreover, they are more engrossed with the drawbacks of working with technology and are opposed to it because they are unable to see the immediate benefits of learning to work with technology.

As the report will show in chapter 4, technology, in that regard, should not be implemented purely for the sake of digitalisation, as that narrative often goes accompanied with dystopian narratives of automation or job displacement. Rather, the task is to make visible how and why technology can be useful when applied to habitual ways of doing, that is, showing how it facilitates rather than reduces mastery.

### **Making visible the benefits and risks of different generations of skills and technologies to different generations of technological professionals**

As mentioned in the introduction of our report, mastery in the digital age is becoming increasingly invisible, and here we see how inter-generational mastery in the CE and PE industries is often difficult to recognise, whether it be in the case of automation rendering the manual and traditional skills appear to be less applicable and relevant for a younger generation, or the older generation being unable to identify the benefits of embracing technology.

On the other hand, we also witness that the younger generation is known for their digital savviness and possesses the ability to pick up digital and technological skills quickly. This is seen in the way participant 21 (ET, CE), speaks about the younger generation:

***We call them Nintendo engineers. Because basically they are just playing, it's like playing a game right. So I don't know if I have a fully formed opinion about that, I see that, I see that they come in and they are the most comfortable with the technology and there is no question. They expect that it works this way. How could you have ever not? Of course it works this way. Whereas with older people then it takes a bit of time, you have to explain, used to be this way and this tool is got to do this bit for you and then you do this. (Participant 21, ET, CE)***

Two things should be noticed.. First, different generations have different experiences with and knowledge of technology. Second, when participant 21 (ET, CE) mentions that the younger generation “expect[s] that it [technology] works this way” he hints at the idea that with being too “comfortable with the technology” comes a certain risk. Technology makes basic processes less visible and may reduce certain areas of one’s mastery; but what if technology fails?

Evidently, each generation possesses their own skills and expertise that are valuable and essential to developing mastery for a digital workplace. Therefore, individuals working in the CE and PE industries must tap on the expertise of individuals belonging to different generations. Indeed, there is so much that the older and younger generation of workers can mutually learn from each other, however inter-generational biases and generational gaps can hinder the development of inter-generational expertise and our report will discuss this further in the next section.

#### **Flow of expertise is layered and multi-directional**

Our interviewees frequently brought up the importance of seniors who had helped them, especially when they joined a company. Some of our interviewees such as participant 07 (ECT, CE) even alludes to the “automatic respect” he has for the senior operators and technicians in his company to the point where he will almost accept and trust whatever his seniors say or do:

*The older ones who have been there much longer than me, they have my respect the minute I step into the site. Because I know you've been there longer than me, whatever you tell me about this machine, I'm going to believe you because you know this better than me. It's not my place to come in, in this position to tell you, you are wrong. To say you are wrong to your 15 to 20 years of experience, just because you are an operator. It's not a good way to have a working relationship. (Participant 07, ECT, CE)*

While the respect and regard for his seniors is commendable and shows his desire and willingness to learn, his admiration when taken to an extreme could also be detrimental to his learning and development as a professional because he does not feel the need to question or examine the accuracy of his seniors’ judgements and decisions. Moreover, if such a dynamic between the ‘junior’ and ‘senior’ was to remain unchanged throughout one’s time at the company, this could also be undesirable given that the ‘junior’ may always feel inferior or not as knowledgeable and experienced compared to his/her senior and thus hesitate to share their ideas or opinions at work, when their ideas may be equally if not even more valuable compared to their seniors.

Mastery being distributed between people of different seniority implies that mastery is not per definition found in only one level of seniority. Instead, both seniors and juniors are potentially equally capable of bringing something to the table and there are valuable skills and expertise that both parties can learn from each other. However, just like inter-generational expertise, this is not well recognised in the CE and PE industries today, given the prevalence of one-way mentorships programs, where it is typical to have someone of a more senior rank guiding an individual in a more junior position. Yet, seniority is different from age given that there have

been some instances where someone who is technically younger in age may also be a senior because they had entered the company earlier or may be higher in rank.

This was shared by participant 33 (MCT, PE):

*We try not to have any superiority, or superficial feelings of feeling that this guy is above me in terms of position, I don't think I should ask him because maybe my ideas will be shut down. You could be the youngest member here, as long as you can prove your idea works, it doesn't matter what the most experienced person says. That is the reason why things can be so fluid, you can be very, very young, an early engineer here, but if your ideas work, basically it works. (Participant 33, MCT, PE)*

This illustrates the complexity and layered-ness of the term 'inter-generational'. When we mention inter-generational in this report, we mean different things at once. First, it refers directly to one's age because different generations in the workforce can have a rather different educational background, diverging customs and traditions, and different affinities with digital technology. These all relate to a variety of ways of seeing and understanding the manufacturing process. Second, when mentioning inter-generational, we also use this term to allude to the fact that mastery is distributed between people of different hierarchies, and that individuals belonging in different hierarchical positions can benefit much from mutual learning and sharing.

It is important to keep this layered-ness of the term in mind when reading the rest of this section, especially because of its implications on learning because we actually pose that the term opens up possibilities for a whole variety in how people can learn, going beyond the idea of an older, senior worker being responsible for training the younger, unknowledgeable and new employee.

The possibilities of this layered-ness are also important when read together with the other sections of this report. Take the positive learning experiences mentioned in section 3.2C where new engineers learned from a spectrum of technicians as part of their orientation, and rapport was built across generations, hierarchy, and seniority. Contrast that with section 3.2B where the perception of engineers as 'brains' and technicians as 'hands' imposed a hierarchy and seniority that impeded the development of expertise.

Having *multi-directional* flows of expertise is critical to tap on the skills and expertise from people in different generations, seniority and hierarchies because it enables one to develop a holistic and comprehensive view of the processes and systems at their workplace.

### 3.3A Overcome bias of older/younger workers

*There is some kind of a flat culture on the shopfloor. People are able to ask questions despite their rank or job level. And people are supported when they need something. Around 11:30am, one of the products built by a technician was tested and it didn't work as planned. In this case, the technician asked for help, resulting in a junior technician sharing his knowledge and expertise to solve the problem. Likewise, I saw an engineer coming down to see what the fault was. Turned out that the wrong cable was soldered. (Fieldnotes, Box Builder, 10 Dec 2020)*

The observation above describes some sort of an ideal scenario, at least for the context of developing inter-generational expertise. The shopfloor at *Box Builder* is described as a flat culture where mistakes can be made and one can learn from and across different generations

and hierarchies. However, as we will show in this section, realizing such a flat culture is difficult because of prevailing biases and assumptions.

### Difficulties of acquiring inter-generational expertise: different visibilities due to different generational affinities, training, and experiences

The root of generational biases in the CE and PE industries lies in the fact that the different generations of engineers have received significantly different types of training and education. Below are some quotes where our older interviewees described their education and how this differs from that of a younger generation. Participant 43 (ET, PE) shares:

*I guess during those days because they're all very manual, we don't talk about technology, numerical control and so forth, so, whatever we learnt, they are the fundamentals of machining. That means we go to basic 101. How you kind of prepare your tool, the tool geometry, how you really grind a tool from a solid bar, how you really design it, so forth. To do your machining in a very basic way, then you gotta do the calculation, what is the right speed, the fit, to do. Those are all very basic fundamentals that we have to go through. If you compare it to today, because they're all technology based and everything is mostly like being made in such a way, they are all mistake proof. Everything you need is all there for you to do. You don't have to worry about how this tool is being made, what's the geometry. You just need to, ok, this part, number, that's it. You don't worry about where this tool comes from, you just use the tool. So that's the difference between those days when we learn or train and today, the technician and the people that do. Yeah, the tools are all ready for them to use. (Participant 43, ET, PE)*

An older generation of professionals working in the CE and PE industries was trained in 'basic 101', from the features of the tool itself and how they are being made to the fundamentals of machining. This is more manual and traditional in nature compared to the way the younger generation of professionals is being trained today. With processes becoming digitalised and automated, there is less of a focus on the features of the tools, basic machining techniques, and how these contribute to the manufacturing process. Instead, there is more emphasis on the operation of these digital technologies in an abstract sense, i.e. the technology has made the concrete process less visible (e.g. because of remote operations, automating parts of tasks, etc.). Evidently, the way that an older generation of engineers was trained is not the most applicable to the CE and PE industries today given that digital transformation has automated the majority of the processes in the plant or manufacturing floor.

This has led to the generations having different ways of understanding what goes on in a plant and, hence, how they work. Moreover, it is difficult for the younger generation to appreciate, much less adopt the older generation's ways of working because digitalisation and automation has rendered past ways of working apparently less directly applicable or necessary. The attention has shifted towards developing technological expertise where skills such as data science and data analytics have become highly sought after (we will explore this in detail in chapter 4 on how mastery is distributed between people and technology).

In addition, as participant 43 (ET, PE) shared earlier in this section, with digital transformation many of the tools have become readily available for the engineers and technicians where there is no longer a great need to understand all the features of the various tools and the basic machining skills. This however does not render the skills, training and expertise of the older generation obsolete:

*But they [younger generation] don't know where these tools come from. In case anything goes wrong with the tool, they actually don't know how to do a lot of the troubleshooting. But for us, because we know how the tool was being made, the geometry that affects the machining, this and that, so when things go wrong, we*

*have the opportunity or luxury because we're being trained, we have the knowledge to understand that. So, when it comes to some of the troubleshooting we're doing ourselves, it becomes more handy to do. So, we have the additional knowledge compared to today, these people are being trained. Because technology is moving so fast, I don't think today's school will teach you how to make the tool. They say, why waste time, just go out and buy 1 tool, only \$20, some \$10, some \$12. Why waste time learning all these things. So a very different background. Because we grew up from the manual era where we had to make our own tools. I mean, tools don't come readily, everything is very special. (Participant 43, ET, PE)*

The deep training that the older generation received when it comes to knowing the different features of the tools may seem ripe for disruption at first glance with digital transformation. However, they have enabled individuals like participant 43 (ET, PE) to hone their troubleshooting skills and it prepared them for solving problems when tools malfunction. In fact, the competent troubleshooting skills that are commonly associated with the older generation are also related to the higher standards of professionalism (*previously mentioned in section 3.1B*) that the older generation of engineers often display at work.

Yet, due to the nature of education and training, these specific skills are more difficult to develop for the younger generation. Participant 53 (Retired, PE), who had left the PE industry in the 1990s shares:

*[When it comes to machining certain parts] students today don't know how to do it. The student just receives the standing product part and just works on it. But how does the part come, the raw materials come about it they don't understand. Okay. Like we learn we start from raw material whatever it is a part steel, stainless steel or carbide. And then we need to go through the process of doing the basic machining, then we have to go through the process of doing heat treatment, we need to harden it to toughen the bacteria, we need to go through the process called heat treatment. Today the younger people don't know all these things. They only know that this is the process, they have to do it, so they just do it. But how the things come about they don't know. (Participant 53, Retired, PE)*

### **Difficulty of overcoming the difficulties of acquiring inter-generational expertise**

While the older generation may be concerned about the younger generation not possessing these basic machining skills and the features of the different tools, they are also cognizant that it may not be the most practical or feasible to introduce these skills and expertise back into the curriculum that current and future engineering students would go through. As participant 43 (ET, PE) shares, in response to our question whether all of these foundational skills should be taught to students:

***Yes and no in a way.** Because if you look at it, technology is moving so fast, there are certain things that we just have to differentiate between the core and non-core stuff. **Because if you want to get everybody to learn everything to basic 101, it almost gotta take you years and years to do. And some people will argue that everything is there for you to do, why are you wasting time learning all these?** Just like the computer. Do you want to learn what is inside the CPU, what is inside the motherboard, correct or not? I mean, those are basic things. But today, if you get a youngster to try to go into there, nobody will care about what's inside the motherboard, what they want is the computer that is fast enough for them to use, with the right software, that they can execute their work. They don't care whether this motherboard comes from Intel or some other manufacturer. So, those are the things that I think, technology has moved so fast, I think that it has become not a priority to do it. In those days, that's where we came from. Because we're all in a manual era, we had to learn all these. Because otherwise we cannot survive. **But today you don't need all that stuff. I mean, it's something***

**good to have in case anything goes wrong.** You can do your troubleshooting if you have some basic knowledge about the motherboard, what is the transistor, what is the thing that affects it. (Participant 43, ET, PE)

As participant 43 (ET, PE) puts it, while the skills and expertise of the older generation are undoubtedly useful, educational institutions may feel that digital skills and training current engineering and technician students on how to operate digital devices and machines with processes that are automated is of a higher priority. He also shares that to train current students in basic machining skills will be very time consuming, something that educational institutions may not be able to afford.

The importance of the skills and expertise of the older generation are becoming increasingly obscured by digital transformation in the CE and PE industries and there is also a lack of opportunities to develop and pick up these skills given that educational institutions no longer teach them. This has led to generational biases where the older generation is critical of the younger generations' lack of proficiency in basic machining and traditional knowledge. This bias goes both ways. For the younger generation – for whom these skills are often inaccessible as they do not have a proper platform to pick them up – the lack of digital literacy in the rest of the workforce may form a basis for bias too.

Just as the younger generation may be lacking in basic machining skills or traditional knowledge, our findings show that the older generation can be resistant and uncomfortable with the increasing prevalence of technology. Unlike the case for basic machining skills and traditional knowledge, whose applicability has become less visible in the modern workplace, the narrative surrounding digital transformation is extremely loud and clear and the CE and PE industries have been inundated with calls to automate, digitalise and the need for workers to pick up digital skills. Rather than being motivated to pick up digital skills, our findings show that the older generation is more worried about technologies and digital devices replacing them and rendering their skills redundant:

*There is also a little bit of fear, especially the people who are older, there is a little bit of fear that these tools are going to come in and replace my job and there's some of that and it doesn't help that sometimes people say that, oh we, we can replicate the work done by a 25 or 35 years' experience engineer, we will run it through this machine learning algorithm, and the answer is we don't need the individuals with 25 years of experience anymore. You know, there is some messaging to that, in fact experience becomes less important and so on which I don't think is necessarily true. It's a bit of a mischaracterisation of the technology but you still hear people saying that and that creates anxiety. (Participant 21, ET, CE)*

Hence, it is evident that the fears and anxieties the older generation may have towards digital transformation have only been intensified by the messages surrounding digitalisation, which may have caused them to be even more resistant towards technology and picking up digital skills.

Unlike the younger generation facing a lack of opportunities when it comes to picking up skills and expertise from the older generation, there are comparatively more opportunities for the older generation to pick up technological skills. However, the difficulty to see beyond experience and expertise is what prevents people from being receptive to learning new skills required in the digital age. It is, in this sense, that a linear understanding of mastery shows an innate weakness, namely the assumption that once one has acquired the status of mastery learning has become unnecessary (cf. Yanow, 2015). This can be seen in participant 41 (MCT, PE) and participant 21 (ET, CE) responses below:

*To be honest when I talk about data science to some of my colleagues, they just brush it off and say that it's rubbish. The hardcore technical engineers would say its rubbish. **They tend to be the ones that are very experienced, that likes to look at hardware, solely because you can't teach old dogs new tricks. So, people that are very technical, that are very old school, will struggle to embrace data analytics, data science.** (Participant 41, MCT, PE)*

*I worked with a lot of people with lots and lots of experience but they can't separate their experience from the, to apply to the digital domain. **They just want to talk about the 30 years of experience that they have about everything and we can't see how that would fit into this technical digital world.** (Participant 21, ET, PE)*

The invisible aspect of mastery is not just due to automation and how it has removed the need for engineers and technicians to perform certain skills and tasks. It also stems from an unwillingness to see beyond one's own skills and expertise. The fact that generations struggle to pick up each other's skills and expertise highlights the lack of inter-generational expertise in the CE and PE industries.

### **Developing inter-seniority expertise is poorly recognized and is fraught with subtleties**

Apart from the challenges of developing inter-generational expertise, our findings have also shown that it is difficult to acquire inter-seniority expertise as it is often not well-recognised in the CE and PE industries. This implies that seniors, rather than juniors, are often viewed as possessing higher levels of skills and expertise. Consequently, the decisions and insights of individuals in senior positions are often seen as more trustworthy and reliable compared to their juniors. This is particularly apparent in the CE industry given the high standards of safety that must be adhered to which leads to one's experience in troubleshooting being highly valued:

*So, on the job training is about gaining troubleshooting experience. You learn from seniors right. They will teach you why you are doing this. **You can question the rationale, why you think that this isn't the best solution or if there could be another way to do it. There's no wrong or right answer but the most important thing is to do it in the safest way because you are dealing with a live plant here right.** (Participant 09, MCT, CE)*

What is noteworthy about this quote is that while he mentions the importance of seniors and the knowledge they share with junior staff, he also acknowledges that there are often no straightforward, clear-cut right or wrong answers in the chemical plant. Some of the current practices may even be questionable at times. Nonetheless, the standard operating procedure or the seniors' ways of working is respected because it is assumed their way of working is safest. However, our interviewees have also acknowledged that their own seniors are not complete masters in their field and there are occasions when the seniors encounter problems for the first time and are not able to solve them. This can be seen in participant 28's (ECT, PE) and participant 11's (MCT, CE) quotes below:

*If the junior has questions, then we ask the senior, or if the senior also sees that the case is the newest one, they haven't seen before, then we go straight to the factory, write up some emails. Then the factory will reply as soon as possible. (Participant 28, ECT, PE)*

In fact, as participant 11's (MCT, CE) quote below will show, his seniors are mindful of seeing themselves as experienced because they are aware of the limits to their experience and that there will always be someone who has knowledge about something that they do not have:

*Even the seniors there, they will never consider themselves experienced. For them, there will always be someone who knows something that they don't know and yeah so, we can practically learn from each other. So, we actually don't see each other as superior towards each other la. (Participant 11, MCT, CE)*

Seniors are undoubtedly important figures in the workplace because of the huge role they play in guiding and teaching new employees. Moreover, their years of experience are valuable when it comes to ensuring that safety standards are adhered to. Yet, no matter how vast the seniors' experiences are, there will always be things that they have not encountered or do not know of. Hence it is especially important that seniors in the CE and PE industries remain mindful of the limits to their knowledge and expertise and be open-minded and receptive to learn from their juniors and people who may have less working experience. Below, participant 16 (MCT, CE) explains the importance of having individuals of different seniority work together:

*We have a good mixture or fusion of people of different seniority and parts of the business, so that's why they invest heavily in the graduate program, so even during this COVID crisis where companies are literally cancelling all of their internships or graduate programs, we do not. They still run their internships. they still run their graduate programs, albeit virtually. but having these people, from different parts, from, from a fresh perspective. I feel like it's something that is necessary, um, by having these fresh graduates into the company, injecting these new talents into the company, but also working alongside seniority that, that the, um, all the people actually possess, that actually brings a nice synchronicity of the different talents but also fresh perspective on set of things. (Participant 16, MCT, CE)*

He shares how his company ensures that there is always a steady supply of younger and more junior employees entering the company because they understand the importance of having fresh perspectives that senior figures in the company can learn from. Additionally, the phrase “a nice synchronicity of the different talents” also alludes to our main argument that mastery in the digital age is distributed across different groups of individuals and each group possesses valuable knowledge and expertise that other groups can learn from.

While our findings have shown there are indeed individuals who are aware of the need to tap on the expertise of individuals of different seniority, our findings also show that companies like participant 16's (MCT, CE) are a minority and seniority bias is still a prevalent issue. Where safety is of the top priority, sticking with tried and proven methods is undoubtedly a practical and wise choice. However, when seniors constantly justify their methods and decisions by saying that “this is how it's always done”, this may lead to further repercussions where juniors become hesitant to share their ideas and opinions with their seniors, preventing seniors from tapping on the knowledge and expertise that juniors may have. Therefore, it can be seen that while juniors learning from seniors is well known and common in the industries, the same cannot be said when it comes to seniors learning from juniors. Hence this shows the difficulties of developing inter-seniority expertise in the CE and PE industries.

This section has discussed the challenges of developing both inter-generational expertise and inter-seniority expertise in the CE and PE industries today. This is due to its invisible nature, where the younger generation cannot see the importance of learning basic machining skills or expanding their traditional knowledge given that automation has made it unnecessary for them to produce such tasks. On the other hand, an over emphasis on following and replicating the way that seniors work may also limit the opportunities for juniors to share their ideas and perspectives, preventing seniors from tapping on the unique skills and expertise of their junior colleagues. Being aware of the limitations of one's knowledge and expertise, no matter age or

seniority, is important as this will motivate one to explore beyond the surface of what is regarded as common knowledge. The next sections explore ways in which we can develop inter-generational and inter-seniority expertise.

### 3.3B Engage in multi-directional mentorship

*The final experiment that the professionals of the Earn & Learn program do is one with the cooling apparatus. It was a rather technical experiment, but something really stood out. Students were asked by the technical executive to throw away the excess chemicals of the experiment into the sink. This obviously is not standard practice and would get the participants into trouble if they were to do it in their workplaces. As a result, they 'fought' with the technical executive, who was like 'never mind it's okay, this one not dangerous'. While what she said may have been true, the fact that it is after all still a chemical and the need to adhere to industry practice lead the participants to resist. The end result was the instructor stepping in to say that while it would be harmless to send it down the drain it was a good thing for them to not do it and conform to industry practice. I wondered to myself that if these were still students, would it be different? Would they have the courage to push back against the executive? Will they do the right thing or even know what is the right thing to do? (Fieldnotes, Pilot Plant, 11 Dec 2019)*

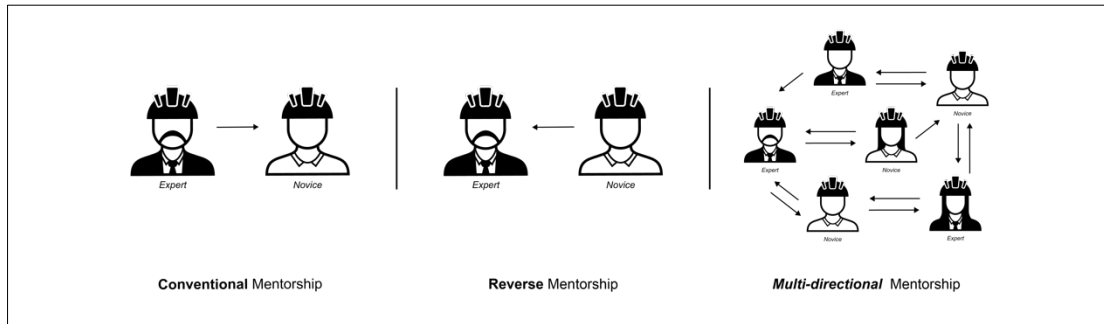
The *invisible* nature of mastery has often made it hard to appreciate the skills and expertise of the other generation. Moreover, seniors are often seen as wells of experience and knowledge, which may prevent juniors from sharing their ideas and knowledge. Given that mastery is distributed between individuals of different generations and seniority, we find that multi-directional mentorships can be potentially helpful in enabling individuals from different generations and seniority to learn and share with each other thus promoting inter-generational and inter-seniority expertise.

A multi-directional mentorship makes sense given that senior and junior workers possess different kinds of expertise. Both are useful and important aspects of mastery. Multi-directional mentorship goes beyond the 'addition' of reverse mentoring – often framed as reverse mentorship, which involves a younger, junior worker mentoring an older, senior worker – to conventional mentoring (i.e., older guiding a younger).

In conventional and reverse mentoring relationships, learning and teaching is typically in one direction, e.g., in reverse mentoring younger workers teach while older workers learn. Such *uni-directional* relationships are often characterised as a “download” from one to the other.

Multi-directional mentorship, on the other hand, is more like blockchain: different pieces of expertise distributed across people. It differs from this one-way uni-directional “download” relationship in three ways (Figure 6).

Firstly, the direction of the “download” is constantly changing. Who teaches and who learns is constantly changing because the problems they are tackling are multi-faceted, and they will necessarily take turns having the relevant expertise needed to solve the different issues that make up the problem.



**Figure 6: Differences in conventional mentorship, reverse mentorship and multi-directional mentorship**

Consequently – and this is the second way it differs from conventional mentoring – multi-directional mentoring is interactive. Using a classroom analogy, conventional mentoring is akin to an old-school lecture. The teacher is the one speaking most of the time, with learners “downloading” knowledge from the teacher. In contrast, multi-directional mentoring is more like the cohort-based learning that is increasingly found in many classrooms today, where collaborative learning, teaching, and discussion is the norm. Everyone chips in interactively and helps advance ideas and solutions together.

The analogy with collaborative learning gives us the third way multi-directional mentoring differs from conventional mentoring. It is integrative. Each must take what each is being taught and incorporate it into what each already knows, and what each subsequently teaches. The new learning cannot be simply added; it must be integrated so that the combined new and existing expertise is more than the sum of the individual parts. Each generation now carries expertise that has incorporated expertise across generations.

It is a more interactive form of mentorship where both parties assume the roles of teachers and students simultaneously, recognizing that they have things to learn and things to teach, together. This simultaneous mentoring process can create a virtuous cycle where, as each member learns more, they use their new knowledge and expertise to teach and learn even more than what they could have if it were only a one-way mentorship. It is also a way to cross the gap between the different types of engineering knowledge that exist in the industries due to different generational expertise.

### Building on senior to junior mentorship

Multi-directional mentorship can build on conventional mentorship. Mentorship in the traditional sense has been unidirectional, specifically from senior to junior. As our findings have shown, senior workers often have the ability to intuitively pinpoint a solution to a problem without going through the list of possibilities:

*I'm going to be listing down everything. I don't have that much experience yet, but they've [my seniors and managers] have been working for 10, 15, 20 years, **they will tell me, this is the problem. And I will say, what makes you so sure?**" and they said, **it's very likely that this is the problem because not, there's no chance in the rest of it having this issue right now. And, they prove, they prove me wrong. They actually prove me wrong. because that turns out to be the issue most of the time. And, that's something you get as well. Because as you progress, you keep using it, you get sharper intuition.** (Participant 07, ECT, CE)*

Having worked at a time when most plants had yet to be digitalized and automated also means that seniors and older workers possess a higher degree of embodied knowledge of the manual processes, where they are able to pass this knowledge down to the juniors through demonstration. It is an effective form of observational learning for the juniors that written manuals cannot provide, as observed during site observations at *Box Builder*:

*The work instructions look really complicated and it was not surprising that he was taking time to understand. **Just then, the senior technicians beside him took the part from his hands and demonstrated the steps to assemble it. As he tells him how to match the two parts before assembling them together, the younger technician is able to understand right away. This passing of this tacit knowledge is obviously lost in the work instructions and can only be understood through the demonstration.***  
(Fieldnotes, *Box Builder*, 6 Jan 2021)

This applies regardless of job hierarchies. Given their longer and often richer experiences, the senior technicians can provide valuable guidance to junior engineers even though the latter may be their superior in rank. Though the engineers technically are more educated in their formal knowledge of the plant, the knowledge learned in school cannot be compared to the knowledge these senior technicians have gained from their effective, embodied experience:

*But your knowledge in school is nothing compared to people on the line, that's doing technical work for the past 20-30 years. So as a fresh grad, you will need to be humble enough to recognise their experience and ask them when you don't know anything. And you cannot be a 'smart Alec' and say oh I know everything. Especially as a new engineer. You've got to be humble enough, stay grounded and ask them if you really need help. It's not an ego thing anymore. For me, and advice to younger engineers, put the ego out of the door when you start work. You got to ask questions. You need to learn from technicians. They're probably your father's age. They'll definitely be more than happy to help if you ask the right questions and if you stay humble.*  
(Participant 41, MCT, PE)

As mentioned before, having a senior assigned as a mentor to a junior is helpful especially in the CE industry where high safety standards must be adhered to lest fatal accidents occur. In the example provided by participant 11 (MCT, CE) below, we see how seniors can help to look out for their juniors which prevents the juniors from making major mistakes. A mentorship ensures that mistakes that workers can afford to make are made, and the ones they cannot afford to make are not. While we only observed instances of a senior to junior mentorship in this aspect, there is no evidence to suggest that the same cannot be applied to a junior to senior mentorship, for example when it comes to working with digital devices, which we will be exploring more in our recommendations.

*So that's why also they assign a senior to you so whatever you do or whatever task is assigned to you, **there is someone monitoring you to actually stop you before something happens.** So basically senior also, in terms of process technician scope, you also have to know things like where is your pipeline going, where is your valve located at, why is this necessary is because in terms of emergency, you know what to do... So practically to be honest, we all, usually, ok to be honest technicians will actually report to their supervisors but then before we report to our supervisors usually we already talk to our seniors. But then before we report to our supervisor we usually already talk to our seniors. So I will try to troubleshoot the issue. Let's say if you can't solve the issue, then we will bring it up to our supervisor. If he thinks that he also can't do anything then he will bring it up to the engineer for a next plan of step.*  
(Participant 11, MCT, CE)

It is imperative to retain this traditional type of mentorship in the CE and PE industries and not forsake it, given that the value of the knowledge and expertise that the older, senior workers can pass on to their younger, junior colleagues cannot be found in curriculums or manuals. Instead, their intuition, experiences and embodied understanding of their work can only be passed on through social engagement, with seniors guiding and mentoring juniors. However, senior to junior mentorship in itself is not enough.

### Building on junior to senior mentorship

Multi-directional mentorship can also build on reverse mentoring. Younger and junior professionals have much to teach and share with their older, senior colleagues. Therefore, it is important that the younger and junior professionals are being empowered and given platforms and opportunities where they can share their knowledge and expertise with their senior, older colleagues. Moreover, our findings have shown that junior to senior mentorship, which is otherwise known as reverse mentorship, has recently started to be practiced by some companies. The premise is that junior workers are more familiar with the digital aspects of work and more tech savvy because they acquired their technical skills in a digitalized setting. The following quote captures what these junior workers can offer as a mentor:

*In our kind of industry, we actually call it reverse coaching, or reverse mentoring. Actually it is an initiative that an older employee of the company is paired off with a younger employee because the younger people are more digitally confident, they are more on social media, they are more knowledgeable about technology, current trends and all that. (Participant 78, Industry Expert, ET)*

Senior workers tend to lack this kind of digital expertise that juniors have. Even without a formal type of mentorship in place, there are also instances where senior workers go to their juniors to seek advice on problem solving. Their familiarity with technology means that they can provide a new perspective to solve a problem:

*Typically, IT stuff, computer skills, they are very good. So if I have any problems with a particular software or something, they will be the first person I talk to, to troubleshoot a problem. I feel like a dinosaur when I'm talking. So they're definitely, they also bring a fresh perspective on problem solving as well. So maybe they are exposed to newer technologies than me. So when they look at certain problems they might have other ideas, which is why we like fresh blood as well. (Participant 41, MCT, PE)*

### How the two combine together

Multi-directional mentorship combines both conventional and reverse mentoring. This section has sought to show how senior-to-junior mentorship and junior-to-senior mentorship are both equally important. Concentrating only on one form of mentorship will cause those working in the CE and PE industries to miss out on a certain expertise and skill unique to a particular group. Therefore, multi-directional mentorship is a crucial pathway to achieving inter-generational mastery as both senior-to-junior and junior-to-senior mentorships by themselves are insufficient in developing inter-generational and inter-seniority expertise.

The underlying assumption with such uni-directional types of mentorship is the 'possessive' view on skills and knowledge: someone possesses a skill that she can then pass over to someone who lacks that skill (Dall'Alba, 2009). This misrepresents the dynamic, complex, and multi-layered process of learning in the age of digitalisation.

When the two forms of mentorships take place concurrently, it becomes a dynamic two-way relationship that provides outcomes that either form of mentorship by itself cannot. When seniors and juniors help each other, their unique skill sets and perspectives build upon each other, we see that this can give birth to a superior solution:

Let's give a very simple example within the O&G industry, suddenly you feel that there is a low flow alarm that is coming, from an unexpected valve closing, or pump failing, or leakage. The important point is that from the older generation, probably they will know that, there are 2 kinds of skills that is necessary - the recognition skills - to select the right information that is presented and form a mental model at hand, and 2nd, the connective skill to forecast what is going to happen next and access whether you have time to implement something. **This is coming from the older people, for the younger people, when they look at this, they have some images in terms of how these things can be implemented, how these things can be enabled using industry 4.0 initiative. So you actually put them together whether it's reverse mentoring or reverse coaching, versus the traditional mastery in terms of mentorship, it does work...** (Participant 78, Industry Expert, ET)

Beyond the transfer of technical knowledge and expertise, multi-directional mentorship helps to eliminate unhelpful biases that each generation might hold against the other and enable individuals to become generally more open-minded and receptive to learning. In order for seniors to not only survive in their industry, but also to thrive, they need to have an adaptive mindset and be willing to learn new things and adjust to changes. Having juniors working alongside them as mentors helps to cultivate that. As participant 16's (MCT, CE) example below shows, having younger, junior workers working alongside those holding more senior positions has been influential in helping the older, senior workers adopt an adaptive mindset. Conversely, as the quote also shows, having juniors work alongside seniors can help them to overcome their intimidation of seniors and encourage them to share their ideas and perspectives which they may otherwise not do so:

**I feel like it's something that is necessary, um, by having these fresh graduates into the company, injecting these new talent into the company, but also working alongside seniority that, that the, um, all the people actually possess, that actually brings a nice synchronicity of the different talents but also fresh perspective on set of things...** My manager has been in our company for 15 years. uh. um. Just my direct manager. My next manager has been in the company for more than 22 years. And these people now are working in the data science field, which literally they are working with solutions that they've not heard 3 years ago. Why? They've been in the company for donkey years. Why? (...) So a lot of these managers who have an adaptive mindset, who are moving with the times, they are the ones who are able to survive, in my opinion, they are the ones who are able to. So, regardless of how long they are in the company, if you have that mindset, I feel that the company can move together. Between the young. Because **I don't feel like the fresh graduates, when they come in, they, they got a certain amount of intimidation from the seniors. We don't feel that. because we actually feel that everyone has a place, a part to play to actually drive the solutions into place. so yeah.** (Participant 16, MCT, CE)

Overall, the intention of having multi-directional mentorships is to convey the idea that, no matter age or seniority, they all have something useful and valuable to teach and share. Hence, this can diminish generational and seniority biases and lead to seniors and juniors treating one another as equals.

### **Building a culture of equal learning, sharing, and collaboration**

Furthermore, having multi-directional types of mentorships can potentially affect the entire culture of a company. When we empower individuals to see each other as equals and capable of mutually learning and sharing from each other, it produces a culture of learning and sharing within the organisation. Moreover, this in turn expands the amount of knowledge and expertise that one can tap on and accelerates the overall pursuit of mastery:

*We don't address people by their seniority for example., we don't, we really have a very low distance power of hierarchy between the different employees. Um. We call our managers by the first name for example., things like that. It's kind of a culture of, um, collaboration where literally everyone is learning from everyone. So, when I come in, I don't have that grad title on my name. People don't even know I'm a graduate; they would just say, ok this guy is a data scientist, he's working on this, what can I learn from me, and for me, what can I learn from that person. So, if he or she is someone who has been in, in the upstream business for 20 years for e.g., and then wants to introduce something new for example., an AI tool into the business, then he or she will call me, ok, yada yada, so it's all about that. It's all about the culture of being able to learn from one another, regardless of background. (Participant 16, MCT, CE)*

Multi-directional mentorships help to ensure that we do not lose out on the valuable skills and expertise that different groups of people possess. It also helps promote an overall culture of sharing and learning within the organisation that is beneficial to the pursuit of mastery. Subsequently, the next section will explore other strategies to develop inter-generational and inter-seniority expertise that also contribute to the development of intra-personal expertise.

### 3.3C Design deliberate failures, mistakes, and challenges that empower

*When everything is set up, the students start running the whole installation first with just water to see if everything works well. Apparently not. After less than 10 seconds one of the rubber tubes disconnects and the water sprays all over one of the students. Everyone, including the educator and the boy himself, laughed very hard. The educator analyses the situation and mentions she knew this would happen. Apparently, the orange tube has an 'out' and an 'in', and they had connected the wrong side to the glass tube, so it disconnected. The wet student asks why the educator hadn't told him before opening the tap, upon which she says that it is the best way to learn something, just like a child who shouldn't touch hot things but keeps doing so until he burns himself. (Fieldnotes, Pilot Plant, 22 Oct 2019)*

In section 3.1A, we explored how the majority of learning in the CE and PE industries comes from one's effective experiences, which refers to the type of work experience that made an impact in one's work performance and caused one to develop mastery at the workplace. The above fieldnote spells out a specific and powerful form of effective experience that can develop inter-generational expertise: deliberate failures, mistakes, and challenges that empower.

In the previous section, our report discussed how multi-directional mentorship can aid in developing inter-generational and inter-seniority expertise. Apart from multi-directional mentorship, there should also be measures in place and embedded within workplaces to ensure that professionals in the CE and PE industries have the opportunity to put into practice what they have learnt through mentorship, which is often informative in nature.

Beyond practical opportunities to apply one's knowledge, our findings show that certain experiences and ways of learning are more effective and leave a deeper imprint on the individual compared to others, and that these experiences tend to be those that involve failures, mistakes and challenges. Moreover, what struck us during our fieldwork and interviews was how the majority of our interviewees and participants frequently brought up their past experiences of failures and mistakes at the workplace when talking about a significant episode that had contributed to their learning. For instance, participant 61 (Intern, CE) remembers:

*The way it works, the fully automated plant, when you key in the results, it will automatically calculate how much to add in and such. But the problem is I gave the*

*correct values, but they were the opposite one. Long story short, if no one had checked, if that had gone through, the product would most likely have been [useless] and as a result it would be a huge loss to the company. But that was in my 2nd week. So, I was let off quite easily. That's one of the most memorable experiences. I remember on that day I didn't even eat lunch because I was so sad. (Participant 61, Intern, CE)*

Evidently, mistakes leave an indelible impression on individuals, yet we are also aware that mistakes cannot always be condoned in the CE and PE industries as this can lead to great financial loss and could lead to serious injury or even death.

In order to effectively make use of mistakes, yet do so in a way that does not lead to grievous consequences, we find it helpful to think about the idea of *designing deliberately* for mistakes and failures into student curriculums or workplace training programs. In practical terms, this means setting up scenarios where one is challenged to such an extent that it becomes likely some sort of error occurs or a mistake is made. Hence, making mistakes and failures are anticipated and when they occur the instructor, senior or educator deliberately does not intervene, unless of course the consequences would be fatal. This allows the individual to go through the full process of making a mistake, understanding the ramifications of doing so, and learning from that process. This is good for bridging the generations, for training and learning, and also gives them access to unique situations they would unlikely encounter in real life, but if they do, they would also be prepared. When designed in deliberate ways, these can be powerful occasions for learning. It is important to be able to do so in a more or less controlled environment, as a *Pilot Plant* educator puts it:

*"Mistakes are ok here. We are a learning institution. But in reality, such a mistake is dangerous and costly, it may be the end of your job. You will notice that sometimes when I see you're about to make a mistake I will question you so you can correct yourself. At other times I'll watch you make the mistake, so you can learn from it."*  
(Informal conversation, Fieldnotes, Pilot Plant, 5 Nov 2019).

Moreover, our findings also show that setting up challenges is useful in enabling individuals to recognise the limits of their skills and expertise and to pick up knowledge and skills quickly. This is in line with what we have discussed throughout the course of the report and section 3.3A in particular, where mastery is becoming increasingly invisible in nature and individuals do not even recognise the limitations of their skills and expertise. Essentially, they do not know what they do not know.

Hence, implementing challenges that involve individuals facing a steep learning curve and solving a problem that is beyond their current skill set can be highly effective in motivating one to pick up skills and knowledge in a comparatively short period of time:

*So as a team lead, what I'll do to help them [my colleagues] level up is that I'll just assign them a particular project where I think they need that kind of exposure. For example, my colleague is not experienced in certain processes, certain machining processes. I'll ask him or her to lead that particular project, so it exposes them to the gaps in their competencies. (Participant 41, MCT, PE)*

Hence, we find that there is great value to designing deliberate failures, mistakes and challenges into work practices or training programs to promote not just inter-generational and inter-seniority expertise but intra-personal expertise and inter-disciplinary expertise as well, which make up the core areas of people-people interactions that mastery is distributed in.

## Designing deliberate failures

At first glance, failures and mistakes may appear similar, and while we acknowledge that they share similarities, our findings indicate subtle differences in the way that our interviewees perceived them. Mistakes are less fatal and consequential as compared to failures. They can be understood as incorrect or unwise actions or decisions. Failures, on the other hand, are events or accidents that take place at the chemical plant or field or when the quality of a manufactured product is compromised.

Failures, in practice, should thus be avoided at all cost. *Deliberate* failures, on the other hand, are relevant and useful especially in the case of the younger generation as they may not possess a high level of embodied understanding or skills, such as troubleshooting, as compared to the older generation. Given that technology has automated many processes, the younger generation of engineers does not get to experience as many hiccups or malfunctions during their work processes:

*If you compare it to today, because they're all technology based and everything is mostly like being made in such a way, they are all mistake proof. Everything you need is all there for you to do. You don't have to worry about how this tool is being made, what's the geometry. You just need to, ok, this part, number, you just check that's it. You don't worry about where this tool comes from, just use this tool. So that's the difference between those days when we learn or train and today, the technician and the people that do. Yeah, the tools are already ready for them to use. **But they don't know where these tools come from. In case anything goes wrong with the tool, they actually don't know how to do a lot of the troubleshooting.** (Participant 43, ET, PE)*

Designing deliberate failures can help to compensate for the lack of opportunities to hone embodied skills. While participant 43's (ET, PE) words on how technology has automated many processes and caused them to be more 'mistake proof' than before, our findings have also shown that the possibility of an accident happening at the plant is still something that cannot be undermined or ignored. This can be seen in our observations at some of the pilot plant classes which we sat in for:

*One student reports to the instructor that a specific valve has just been opened and the instructor asks if he is sure. The student is sure and the instructor asks the other students to come join. The instructor whispers to me [the fieldworker] that the students do not seem to have a clue about how their actions are connected to those of others, that if they open a valve here it has consequences there. **Apparently, the student was right in that the valve was opened but he had opened the wrong valve. The instructor gives a friendly speech, although he makes sure to get the message across: "You all need to be more aware of your actions. If we do something wrong here it is not a very serious problem. We don't work with very hazardous substances and it's a simple system that is easily set up again. But in a real plant... A mistake like this may cause a shutdown of the plant and costs hundreds of thousands of dollars. It can also cause hazardous situations for yourself and your colleagues, so you must know the consequences of your actions"**. (Fieldnotes, Pilot Plant, 29 Oct 2019)*

From this example, we can see that the instructor deliberately does not point out the mistake initially but highlights to them the consequences of their actions after. Moreover, his speech to his students reinforces our earlier point that the possibility of accidents or shutdowns happening remains real if one is not careful. In other words, whereas the experience of a failure in an actual plant would be an extremely powerful learning opportunity but an even more extremely costly one, in a controlled environment such failures can be replicated as a means to learn.

Moreover, participant 23 (Retired, CE) shares with us the harsh and rigorous training process where he was put through:

*So, what they will do to you in the training right, they will psycho you. They will do this mock-up simulation of the rig situation, and they will, **they will purposely screw up your job although you plan everything perfectly, screw up your job and see how you deal with failure.** I'm serious, that was how, that was how, how they would psycho you. And the trainers would keep on psyching you, and repeatedly question you like "what are you doing, you are doing it wrong" even though you are actually doing it right. But he just tries to question you and test you. And he will make you work, running here, and there, like an idiot. **Once you have done everything smoothly, he will go behind your back, and just turn off something, and you have to fix the problem. Why? What this is to train our mental toughness. And I see that in my company basically, everybody who leaves the company, we can see that become so much tougher mentally.** They do this because they know that your job may go wrong someday and it's how you handle that right. So, that's the key part, the behaviour, because uh, I don't know whether you have seen it before but people when they are under stress, they become very panicky (...) You survive school, then you go into your functions, you come back to wherever location you are from, then your manager will drill you again. The actual manager will drill again for 3 months. He will supervise you, drill you. When he sees you are ok, then only you are allowed to go to the field on your own. (Participant 23, Retired, CE)*

Unlike the previous fieldwork example where we see the instructors deliberately not intervene to correct their students' mistakes and allow these failures to happen, participant 23's (Retired, CE) example is one where the trainers would deliberately manipulate their trainees work processes and in his words "screw up their job" and even go behind their backs to do something when they are unaware to watch how they would respond and handle the situation. It was not just about communicating to trainees the possibility of encountering failures, but it puts trainees directly into situations of failure and accidents, not even of their own doing, to see how they would respond. Therefore, it goes beyond merely focusing on the possibility of failure occurring. It trains trainees in a way where they become well-equipped to handle failure when it occurs. Participant 23 (Retired, CE) shares that the rigour of their training is due to the nature of his work as a field engineer where he often encounters situations where his colleagues may make a mistake that has potentially fatal consequences:

*A lot of people, they will try to cover up, and that would make things worse. That's the problem. That's the problem I see in the oil field. They try to lie. Once you lie, you need a bigger lie to save the initial lie... I deal with explosives, we work a lot with explosive, that means detonating charges, eh, connecting all the wiring for explosives, we deal with a lot of radiation, we are used to run this, we used to run a, what we call, a 'mini-tron', which eh, which basically sends out neutrons. for example. I forgot to turn off the tool, I come up, if I come up, that means when I am taking off the tool, I forgot to turn it off, everybody who is 1m beside this equipment will die in 1 week, ok. So, there are a lot of these kinds of things involved. so. What the company does to train you initially is they will try to force you; they will try to pressure you into making mistakes. (Participant 23, Retired, CE)*

Preventing failure and accidents is important in the CE and PE industries. Therefore, the intention of designing deliberate failures into training programs and school curriculums is to have young professionals and students go through 'failures' to understand the severe consequences of it. To, in a sense, embody something that hopefully will never happen so that it will remind them to always remain alert and conscientious in their work. There is often no room for failure in the real world. From this viewpoint, it is evident that designing deliberate failures also reinforces the importance of pursuing high standards of professionalism in work, where one does not cut corners but adheres faithfully to the standards that are expected,

discussed in section 3.1B. Even in the event where failures do occur, students and young professionals would have previous experience and would be more equipped to handle them. It is noteworthy to mention that learning from failures become even more rare in digitalized processes that are streamlined and automated; the technology aims, with good reasons, to rule out errors. But when they occur they must be solved by people who have experience with such troubleshooting.

### Designing deliberate mistakes

Mistakes are more commonplace than failures and accidents and sometimes even seen as necessary in the learning process. While failures were always sternly cautioned and taught in a way in which they had to be avoided at all costs, there is a higher tolerance for mistakes and many of our participants acknowledge that mistakes are a double edged sword.

In our data, we identified two ways in which interviewees talked about mistakes as a valuable learning tool. The first way is when an individual commits a mistake and has to bear the consequences of that mistake. However, precisely because of the fact that one has to bear the consequences, the mistake left an indelible impression on them and pushed them to become better in their work so that they will not make the same mistake again:

*A very good example that I can give you is planning the orientation of piping. Back then when I was in my 1st year in this job, I had some tasks where I had to plan how the piping worked, how the piping ran, and within all these piping there were a lot of other equipment going on. **In the 1st year, I had to keep revising the way I put my piping. Because it's not operable. In fact, I actually incurred extra costs for my project and my boss was not very happy about it. So, what happened was that we had to cut down the entire piping to do the modification, and in the end the modification itself was even more expensive than the piping installation in the first place. So that's the painful lesson learnt. So, after that, the next project that I did involve piping that was even more complex. But I could tackle them better and in fact, I started using pipe software. CAD modelling software, 3d modelling software, to start drawing 3d models of the piping so that I can imagine how all the piping would go, how all the equipment can be placed. That is what I started doing. So, in the case that lets say, things that cannot really be imagined on site, when you do that in 3D modelling, you can immediately foresee a lot of things and eliminate most of them. I wouldn't say you can eliminate all of the unforeseen circumstances, but these are the kinds of different practices that I've taken, and it helped me along the way especially for the piping planning. And it also helped me, giving me knowledge on how other places, within the site, can improve them even further. So, when some other site, some other parts of the site have some legacy, something that's been there for more than 20 years, I can immediately see that, hey, actually these are not good. And we can immediately change it to a better one. And I already know the solution right from my head. Because I can – I've already done so much piping work.***  
(Participant 15, ECT, CE)

While participant 15's (ECT, CE) first experience with piping where his work did not go as desired was undeniably a painful one, it also spurred him to do his own research and pick up different software skills that sharpened his piping skills and caused him to become well-versed with piping such that he now has all this knowledge at his finger because of the work that he had put in. Hence, it is evident that while mistakes may often lead to negative consequences in the short run, if used effectively as a motivator to better one's skills, they are undisputedly very valuable learning tools in the long run.

The second way in which interviews talked about making mistakes is where one is encouraged to make mistakes right from the beginning and they can make mistakes without fear of punishment. This concept is otherwise known as psychological safety (Edmonson, 1999) and having psychological safety has shown to create a conducive environment for workers to learn

and grow through making mistakes and failures, where they also end up making less mistakes in the future. Below is an example provided by participant 42 (MCT, PE), sharing how his company uses mistakes:

*And we are spending a lot of resources in training this because not having experience means we make a lot of mistakes. Mistakes are very very expensive in a hardware company, so we are willing to take the cost, because we feel like the value add on these people would be much higher. (Participant 42, MCT, PE)*

The example shows how resources and money are intentionally set aside to accommodate mistakes in the manufacturing process in his company. While he acknowledges that 'mistakes' are often very costly, they are willing to bear the cost because they are often necessary to the manufacturing process. Allowing employees to make these mistakes is very beneficial to their learning. Therefore, employees at participant 42's (MCT, PE) company are given the psychological safety to experiment and make mistakes knowing that there has already been money set aside beforehand to accommodate these mistakes. In addition, the example by participant 32 (ECT, PE) shows the benefits of making mistakes in greater detail:

*So when the company 1st started in the sense, we came in all as undergraduates. So there was not much expertise, no one here with like 10 years of experience to actually guide us along and people are thrown like a full blown task, we need to manufacture a full size robot and also. So we actually iterated through 13 or 14 designs and at that time [our boss] actually gave them a mechanical team the capital to really manufacture the part. So whatever they drew, whether it works or not they will send it out and it will come back and see oh no something is wrong. Ok sure next design next design, it's really through this process, they keep drawing and sending and drawing and sending. So because of this the deadline is so tight because they need to meet this timings to keep doing this you know. But along the way they will learn like, oh we shouldn't do things this way, we shouldn't do things that way. I am not going to head in this direction because I know this certain doom or this is a slightly smarter way to do this kind of thing. (Participant 32, ECT, PE)*

Mistakes are useful because they teach us the wrong way of doing things and how we should not go about doing certain things. Beyond just knowing the correct way of doing things, it is equally important to know and be aware of and, indeed, to sometimes *practice* the wrong way of doing things. Knowing so will make one's work processes more efficient in the long run. As participant 32's (ECT, PE) example shows, his team started off by making many mistakes which caused them to go through multiple designs. However, along the way the past mistakes helped them better understand and streamline their work processes and caused them to be more aware of which pitfalls to avoid. Moreover, the lessons learnt from these mistakes are being further passed down to the newer colleagues who join their company, where they do not have to "waste time" and go through the long, arduous process their seniors had gone through.

### Designing deliberate challenges

As we discussed previously in section 3.2 on the importance of developing inter-disciplinary expertise, given the highly interconnected nature of the CE and PE industries, it is not uncommon for someone to be part of a project that is outside their discipline or have to apply skills and knowledge which they did not receive any former training in. Apart from having safe intersectional spaces to enable individuals from different disciplines to come together to learn and share with each other, our findings have shown that a current strategy used to accelerate the process of learning a new skill or picking up new knowledge is to intentionally place someone in a challenging situation, which is beyond their current skill set. Challenges or 'stretch assignments' can be viewed as opportunities to test one's 'limits' and to assess how much one is capable of achieving when they need to come up with novel ideas and use their

strengths productively in different ways. Challenges are also useful in building 'agility', which is the capacity to be flexible across different situations and operating environments. Hence, growth and development take place when employees are given assignments that are different from their typical responsibilities and stretch existing abilities:

*And that's the same reason why a person who is a fresh graduate, for example, engineer D, when he joined, had no experience in 3d printing. But he is the one who designed the [Robot] model, so you know like when you throw at him, it's actually a \$1 million spent that he's going to make and then if he screwed it up and the whole project just falls apart. **So that's the sort of responsibility we actually put on each of their heads that you know they have to take the sense of ownership. And that's the reason why you see everyone working really hard because they know that they won't get this sort of opportunity elsewhere. So they are very very faithful towards it, they respect their opportunity, they want to do the best.** So even if it's an intern, let's say we had an intern who just joined I think two weeks ago. Whatever he designed in the first week of internship has been incorporated into the robots locally. So that's why we keep saying everyone here has almost like three years of experience. So if you spend one year you have learned at least three years' worth of experience elsewhere. (Participant 42, MCT, PE)*

Challenges are effective because individuals themselves feel a sense of trust and expectation from their colleagues or superiors which serves as a great source of motivation to push them to try one's best. They do not want to disappoint their colleagues. At the same time, challenges are valuable opportunities that they may not have access to at their position elsewhere. Hence, those that are given challenges are exceptionally thankful to be given this opportunity, which translates into them working extra hard to live up to the expectations. Moreover, challenges need not always be inherently difficult with extraordinarily ambitious goals to reach. More often than not they are tasks that simply involve one being in a situation outside of their comfort zone.

As we have discussed in section 3.3A about the difficulties of developing inter-generational expertise, our findings show that the fears and anxieties which the older generation may have towards digital transformation have only been intensified by the messaging surrounding digitalisation, which may have caused them to be even more resistant towards technology, much less pick up digital skills. One of our interviewees shared how he had successfully managed to encourage those who were initially resistant towards technology to pick up several new skills:

*I've seen it quite a few times already, they really – a lot of new things (technology) being rolled out every few months, that kind. **And most of the time, people are eh, I don't feel like trying, the first few times. But then slowly, you let them get used to it, it becomes their new norm. And they actually realise eh this is much better than last time. So for most of the technicians at least for the technicians on my side, the general pattern is like that. Then after a while they realise actually this is quite user friendly and they are not very against it. Of course at the start they will have the inertia to go and learn this new thing (...)** We just say by this date, usually this is a common practice, by this date, we will phase out the old one. You no longer look at the old one. So you have this period, this amount of time to learn the new system. **But of course we wouldn't make the new system very difficult. Like learning a totally new software. It's not like that. It will be just a very simple kind of upgrade.** For example last time maybe you did data logging through paper, then you wanted to go to the PC and write everything. But now you have to use an app. So you use an app, then you log in the location, you can key in the data. So, that is just 1 example. Yah this, we make sure all of these apps are user friendly, so that they can really pick it up fast. (Participant 15, MCT, CE)*

Compared to the previous example by participant 42 (MCT, PE) of a new hire in his company being assigned a project worth \$1 million dollars, participant 15's (MCT, CE) example appears to be the complete opposite where the new skills that his colleagues are required to learn do not appear to be very complex or "challenging". Hence, participant 15 (MCT, CE) deliberately exposed the technology to his colleagues in a gradual manner so as not to overwhelm them except giving them a deadline by which they should have learnt and become familiar with the technology. Yet he is also aware to not introduce to them technology that is too complex and inaccessible to them. Therefore, the example shows that for challenges to be truly effective, they need to be tailored to the individual's ability and capacity. At the same time, it shows that challenges are not just applicable to the younger, junior generation to develop their potential but the older, senior generation can also benefit from challenges because of its ability to empower them to continually learn and pick up new skills, especially in the digital age.

Lastly, designing deliberate challenges is important and essential because even if they are not deliberately designed, one will inevitably find themselves in challenging situations at one time or another in one's career, where they may be involved in a project or task that is outside of their discipline and training:

*Some of the things because they are just too specific they cannot be taught in school. So what they do is to teach the principles where it is applied to the vast majority of the processes but again not everything is covered in universities. So some of the things you have to learn on the job or just before the job. (Participant 04, Student, CE)*

Student curriculums and training programs will never be able to cover the full spectrum of skills that one will need in their career. Therefore, more than technical skills, it is important to develop the skill of learning and to be able to pick up new skills in a quick and efficient manner for professionals in the CE industry. Therefore, designing deliberate challenges not only stretches one's capabilities and skills beyond their current skill set, it also hones one's ability to learn and teaches one the skills to be able to pick up new skills and knowledge in a short period of time which is highly valuable in the CE and PE industries.

### 3.4. Conclusion

In conclusion, chapter 3 has covered, firstly, how mastery in a digital age is distributed between a wide range of people and, secondly, how this distribution is constituted between these actors. Specifically, we have illustrated how these people-people interactions involve:

- 1) Develop intra-personal expertise;
- 2) Develop inter-disciplinary expertise; and
- 3) Learn through inter-generational and inter-seniority expertise.

At the same time, chapter 3 has also discussed the importance of acknowledging these different types of expertise and the need for developing them concurrently. We also identified some common struggles and difficulties associated with the above and described several measures that may be helpful in addressing them. While digital transformation has placed disproportionate emphasis on certain skills and attributes, it is imperative to remember and discern what types of skills and expertise continue to be critical, even though less prominent, in ensuring safe and quality manufacturing processes. At the same time, it is imperative to be open-minded and to be aware of the limitations of one's knowledge and expertise so that individuals continue to remain curious and motivated in picking up new skills and knowledge that may not be the most readily apparent and applicable. As a whole, the three main interactions constituting expertise reinforce how mastery has become increasingly *distributed, multi-faceted and invisible* in nature. This is a process exacerbated by the digital nature of contemporary technology, something we will further detail in the next chapter.

## 4. Multi-faceted expertise distributed in people-technology across contexts and settings

In this section, we will be focusing on technological advancements and the interactions between people and technology. Given the distributed and multi-faceted nature of expertise that we have established earlier in this report, it is important to note that the term 'technology' refers to technology and technology use at different scales, from the use of impending technologies in future work systems to the effects of technology on human capabilities and diverse work environments.

What struck us about our respondents' perceptions of how mastery related to the use of technology was how different they were from the popular perception promoted by those outside of the industry. These differences are detailed in this section, and collectively paint a more sophisticated picture of the relationship between mastery and technology.

In one particular instance during a field observation session at *Box Builder*:

*We were caught rather surprised at how one technician mentioned that "he had no qualms with technology as technology is too complex for his understanding" (Fieldnotes, Box Builder, 15 December 2019)*

This poses a rather interesting paradox as the very job that the technician does is to build a *technological tool*, yet the technician perceives the building process as a mechanical process, instead of choosing to see technology as an *electrical process*. It thus becomes crucial to better understand how technical professionals see technology. Broadly speaking, the findings in this section indicate that technology in itself is of less concern to professionals than how technology relates to what they do and how they do it. Technology use then is a central concern in investigating the impact of digitalisation on mastery.

In addition, our initial series of field observation sessions conducted with *Box Builder* and *Cub Cleaner*, both of which are PE manufacturing firms, also showed a different execution of technological advancements used within the companies: many of the advances came not from the latest technologies, but on tried and trusted traditional building processes and work systems instead. This was an important insight that revealed to us how the popular perception of digital technology is very technology-centric and shows limited understanding of technology at work. Untangling this further helped us expose the bias and preconceived notions about how automation and augmentation technologies are used and should be used in Singapore's manufacturing firms.

Moreover, we have discovered through subsequent field observations that when the latest technologies are adopted, steps have been taken to ensure that they are integrated within the companies and existing practices, so much so that exposures to new technologies have seamlessly become invisible. This creates a subtle new challenge for developing mastery: as people and technology become more and more embedded in today's work settings, more and more of what we can observe as expertise will be obscured.

The above differences and subtleties must be accounted for in order to attain mastery in the digital era. Hence, in this section, we identify how this can be done in two main areas of people to technology interactions in the workplace:

- 1) Experience, understand, and use technology intimately, independently, and intelligently
- 2) Understand diverse work environments (plants, products, processes, and increasingly places)

#### 4.1 Experience, understand, and use technology intimately, independently and intelligently

As the CE and PE industries undergo digital transformation, our research has been interested in studying the impact of technology and the automation and digitalisation of processes, particularly in terms of how the combination of the above has threatened, challenged, or enabled the development of deep skills and acquiring mastery.

However, In our interviews and fieldwork observations, we saw distinct differences between the above and how participants perceived, understood, experienced, and used technology. Our interviewees and participants have tended to lean more towards the possible impact of technology on making workers redundant, making processes more efficient, and what is the latest technology available and which ones to adopt. This is in line with Oriloswki's (2007) argument that technology has been commonly studied in terms of adoption, diffusion and use within and across organisations. Technology use, here, is primarily looked at through a techno-centric lens, i.e. how it impacts what professionals do, instead of their impact on skills and expertise. Our usage of the term technology use is broader and, in line with Orlikowski (2007), looks at the entanglement between technologies and practice. This provides the basis for a less deterministic view on technology, and below we explore some of the issues our study has highlighted in this respect.

#### Differences in what participants initially thought would happen versus what actually happened (technology determinism versus human adaptability)

*We started our apprenticeship in the 70s you see, during that time it was very manual (...) Yah we were very worried when we went into computerised training. We are very worried that we would press the wrong button because when you press the wrong button the machine will crash (...) But if you think that oh my manual skill is very good, it's good enough I won't need to learn computerised processes but as years go by, your skill becomes obsolete. So it's better, it's not whether you like it or not. You have to know that as the industry progresses you have to follow. When this is the direction of the trend you have to follow. (Participant 47, ET, PE)*

It is telling that participant 47 (ET, PE) arguably had similar concerns as other generations of new technology since the 1970s when he first encountered Computerized Numerical Control (CNC) machines, but each time he has mastered the skills needed.

When queried on how it was like transitioning from manual to CNC machining, participant 47 (ET, PE) recalls how he was initially hesitant to operate the machine because of his lack of familiarity. In addition, when queried further if he felt worried about the possibility of the machine being able to perform the same tasks as him, he responds that no matter how good one's skill is or whether one has the desire to learn, one simply needs to adapt to the changes and the direction that their industry is heading towards:

*So how it [digitalisation] changed my work? I mean I have been through 2 years in this digital area right, only the last 2 years. **Before that I was doing everything by manual. There were bits of technology that came in every now and then. Using the cloud for certain pieces and you didn't think too much about that at all. It just came in in drips and drapes and every now and then there's a bit of an update and you***

***pretty much carried on as normal with a little bit of a new update. So I am now right in the thick of it. So every conversation is about some type of digital technology because you are going through the midst of it. You are just more aware of when you see the ground, because you are just more aware that it exists. Before that I didn't even think about the fact that it exists. So yah it's that part of it that has changed for me. I didn't think about digital until now. (Participant 21, ET, CE)***

On the other hand, participant 21's (ET, CE) quote above details how he had transitioned from manual work processes to digital work processes.

The differences between participant 47 (ET, PE) and participant 21's (ET, CE) initial views - including some worries - towards new technologies, and their subsequent views after they had used, understood, and experienced them were also apparent. While the transition for participant 21(ET, CE) was not as drastic as compared to participant 47(ET, PE) in the example above (he did not "*think too much about*" the different digital initiatives that he had to pick up when his company started introducing them), what is similar in both cases is that they just got on with using and mastering the technologies. What is also similar in both cases is they are both aware of the *prevalence* of technology, rather than how technology has affected their skills per se. Their actual experiences also stand in stark contrast to what they initially perceived and with what is popularly perceived outside of their company and industry.

#### **Barriers: incomplete and inaccurate understanding**

This suggests that in general, there is a paucity of an intimate, independent, and intelligent understanding of technology use, specifically how technology has changed one's skills and expertise and how this has in turn changed the way one uses technology and the meaning of technology as a whole.

This is concerning given that an inaccurate and incomplete understanding of technology use will limit one's ability to develop mastery in the digital age.

Orlikowski (2007) provides an example from a research study of a company who had issued blackberry devices to a fraction of their staff back in 2000. She posits that in the process of examining the communication practices of the employees, it became increasingly apparent that attempts to understand their habits in conventional 'media use' terms had left out important aspects of what they were experiencing. Specifically, viewing the employees as 'using' their BlackBerrys to communicate with each other significantly overlooks how their communication practices have been substantially reconfigured through their engagement with BlackBerrys. This reconfiguration also impinges on making parts of the process invisible, such as informal or spontaneous workplace interactions. This is especially important taking into consideration the people-people interactions described in the previous chapter: these are crucial interactions for developing mastery, but they also tend to change when becoming more digitally mediated.

Therefore, it is essential that we do not study digital transformation in the CE and PE industries only through the lens of individuals using technology, their attitudes towards technology and the type of technology that they are exposed to, but also seek to understand how their practices of using and interacting with technology have transformed ways of work, skills and expertise, and using technology overall. For instance, technology can change, for better or worse, the ways in which we engage with our work environment. Skills that once were deeply embodied and grounded in a physical work context (e.g., the technician being able to 'feel' the process, or to 'smell' or to 'sense' a problem from a mile away) are transformed in the sense that technology moves the technical professional away from the plant or factory. They thus

change our competencies and capabilities, specifically in the context of how in practice we often draw on our embodied experience of it.

This section will focus on how mastery in the digital age necessitates discussions beyond adoption, diffusion and use of technology within and across organisations. Instead, with a focus on mastery, we need to consider how technology is used, understood and experienced by technical professionals and how this relates to their intimate, intelligent, and independent examination of technology and its effects on work practice. Understanding how technology is used, understood, and experienced and how technology has transformed work processes is essential to understanding how one can go about developing mastery in the context of ongoing digital transformation in the CE and PE industries.

#### 4.1A Understanding technology's impact on human competencies and capabilities

*Few minutes of watching the robot go down one step at a time, and each time, both engineers discuss and possibly study/revise the codes and look at the movements of the robot again. I was already pleased to see the robot moving autonomously down the steps. But one engineer seemed to notice the space allowances behind the robot as it glides and thuds down a step at a time. And I think this is bothering him, warranted some attention, and fixing. So, basically, I would say, as one gains experience, this is enacted in how one carries out work. The little improvisations and that drive for perfection seems to come with knowledge and experience - possibly knowing what to look for or noticing what should not be there ideally. (Fieldnotes, Cub Cleaner, 9 Dec 2020)*

Discussions about technology with our interviewees and fieldwork participants tended to revolve around adoption, diffusion and use within and across organisations. There is less discussion on how that technology might account for the different expertise of the different technology professionals using that technology, such as that of the field observation above.

Participant 82 (ET, Other Stakeholder) shares from her experiences with the PE industry in Singapore:

*So again 10-15 years ago, in the wave of nanotechnology, I found that a lot of the companies really, need to be, I guess for the lack of better words, need to be **educated more beyond what you hear and read on the surface**. Same thing that I see happening now with digitisation. Actually, a lot of outreaches, a lot of transfer of knowledge are needed. Many companies don't really quite know what they don't know. So, you know, quite often you, a company read about oh you know digitalisation, additive manufacturing is going to be this and that, it's going to be disruptive. **But it is necessary for companies, especially the smaller scale companies, to get access to a deeper analysis of the technology.** To really understand and know what it means to them and what they need to be ready to adopt or to ride on the wave. Ok, quite often with my interactions with companies, companies who come to us and say we would like to do this and then you realise that their understanding is a huge gap between what they interpret the technology could do for them. (Participant 82, ET, Other Stakeholder)*

Participant 82's (ET, Other Stakeholder) response, together with the responses and sharing in the preceding paragraphs above, highlights that there is an opportunity for professionals/companies in Singapore to be more astute beyond what they hear and read on the surface about technology, and should aim to have a deeper understanding of the technology that they hear about and are interested in. What this implies is that they need to independently, intelligently, and intimately understand how the different types of technology

apply to them, specifically whether or not it is appropriate for them to adopt these technologies and how the technology will impact their work processes.

Such an understanding must consider the impact on human competencies and capabilities and it can be achieved. This can be seen in the quote by participant 15 (MCT, CE) where he shares his company's decision making process behind the technology they adopt:

*Let's say in terms of – for the technician, a lot of times when we do those upgrades including the ones that I'm doing, we are always thinking about 1 thing. Whether it really makes the technicians' life easier. If it doesn't make their life easier then there's no point, we do this upgrade in the first place. The whole point of having all these upgrades, is that it adds value. It eliminates all these errors; it makes our technicians' lives easier. It increases productivity. It increases efficiency. So, these are the kinds of things we really look at. So, if let's say somehow, I need to learn a new skill on a new software and you really need to take your time to go and learn it, but whatever you already have now is ok, then yah la, most people won't go and learn it. But let's say the new skill you need to learn is fairly simple and it's even easier than what you're currently doing, you just have to push them a bit to use this skill and if they're already okay with managing whatever they're doing now, then they shouldn't have a problem learning these new skills. (Participant 15, MCT, CE)*

Participant 15's (MCT, CE) response reveals that his company is very discerning about the type of technology that they adopt, where they want to ensure that the technology that is worth adopting makes current work processes more efficient and truly benefits employees.

Similarly, participant 17 (ET, CE) is also well-informed of the tangible improvements that technology has brought to his work processes:

*Doing lab analysis is so incredibly tedious. not because it's very hard to do, but because you have to do so many samples. right. and, and also make sure you are accurate, because these little amounts of water that you took, you have to put 3 drops of this, 1 sachet of this and make sure, sometimes you forget and then you have to redo it again, ugh, it's very tedious, all right. especially when you don't have help. um. so that's the part that is becoming automatic right now. that's the part that you don't have to do anymore, right, so basically, you have all these analyses being done and then what automation is giving you now is that it's comparing 2 trends, oh, 3 months ago you have the same situation, and this will happen in the system, you can visualise things faster. so, you can be faster for making recommendations on time, being more opportunistic and then, second, you have more time to go and talk to your customers to understand more from their side. because before, you were so busy working on your data that by the time you get to your customer, it's quite late already, it's almost like 5pm, your customer wants to leave, you want to leave, so there is not much time for conversation. but now you have more time to sit down, look at the trends, look at the data, be more analytic, create a bit of relationship with your customer, ok, understand more from their eyes, what's their perspective, what is their, um, goal, and be more valuable. (Participant 17, ET, CE)*

In this section, and as hinted at by the two previous quotes, we look at the impact of technology on specific tasks. That is, rather than looking at technology in an abstract sense - which, as we have argued, often looks at technological trends or adoption - we look at its more subtle impact on human competencies and skills.

### **Pinpointing impact at the resolution of tasks**

Participant 17's (ET, CE) experience gives us further insight on how we can understand technology's impact on specific human competencies and capabilities. More than merely being aware of how technology can automate the otherwise especially tedious process of lab analysis, participant 17 (ET, CE) can also pinpoint the exact tasks that his technology is able

to perform. In addition, he is also able to articulate how the different functions of technology - the computer comparing across trends from different time periods and providing future predictions - will shape his work processes and enhance his ability to “visualise things faster”, provide recommendations more quickly, and be more opportunistic in his approach which enables him to understand his customers’ needs more deeply.

Understanding how technology impacts human competencies and capabilities involves being cognisant of the specific tasks that technology performs and how it compares with the manual way of doing things previously. This includes knowing what were the tasks previously being performed by humans that technology has since replaced and what is the difference in output between both methods. On top of that, one also needs to recognise that technology’s ability to perform a certain task will in turn shape other work processes, in particular, the tasks that one “does not have to do anymore”, the tasks that one must still continue to do and the additional responsibilities expected of one now that technology has taken over some of the previous tasks that one used to do.

Participant 17’s (ET, CE) previous example on how lab sampling had become automated at his workplace, details how the computer can now compare across different trends, look at past events and predict future situations. One must recognise that technology taking over or performing certain tasks for us also implies that the frequency of performing these tasks will become increasingly less, and there will be increasingly fewer opportunities to hone these specific skills. Hence, it is probable that participant 17 (ET, CE) and his fellow colleagues will be performing lab samples and analysing and predicting trends less frequently and they may not have opportunities to develop these skills and attributes at the workplace.

### **Understanding the impact is also understanding where we can become complacent (and more worryingly, where we are unconsciously complacent) and associated risks**

Understanding the impact of technology on human competencies at the level of tasks has an additional benefit. Some of our interviewees argued that the adoption of certain technology at their workplaces has caused individuals to become complacent and over time neglect foundational engineering skills because technology is able to perform all these tasks for them. This can be seen in participant 14’s (MCT, CE) example below:

***And the worst is that they say that certain phenomena are correct, because the tools are correct. So, like, for example, why is this happening, so, you may say, yeah because the software says so. I mean, this is not acceptable because you have to go on further. The software says so, because? Why? Because why? And then, as you start answering all because, then that is where you make use of your basic knowledge.***  
(Participant 14, MCT, CE)

Participant 14’s (MCT, CE) example highlights the potential pitfalls of technology – one can become so overly dependent on technology, where they start to trust and rely on the results generated by technology rather than depend on their own engineering judgment. Participant 14’s (MCT, CE) example focuses on professionals becoming complacent. Even more worrying is that in some cases, the complacency is unconscious and is there right from the start:

***But the thing that you mentioned about all these training sessions, because these people, the unfortunate portion, when you go into the work floor, because of the short span of time, most of the so-called more senior people will teach them how to do it. How to do it means they go to the machine, for example, just remember ah brother, just press A, C and D. don’t do any other thing. Anything happens, press A, C and D. but this guy will not know why A, C and D. correct. So, the worst thing is that – I mean I’ve seen some of these things, sometimes we are also quite heartbroken. After then they joined us, after working 3-5 years, they say eh why doing that? 5 years ago, I remember this guy trained me, everything I do must press A, C and D. Why A, C and***

*D? don't know. Anything goes wrong? Don't know. But it works. They have been pressing for 5, 6, 7 years and it works. It churn[s] out popcorn like that. Every time it works. But when things go wrong, you don't know why A, C and D. Why not A, B, and D? correct or not? So, they know how to do it, but they don't know why they are doing that. So, the lagging part of this in the industry in terms of training is the why portion. And the why portion must come from education and knowledge.  
(Participant 43, ET, PE)*

Participant 43 (ET, PE) shares that the way junior and younger professionals are trained to use technology shows a lack of emphasis being placed on recognising technology's impact on human capabilities and competencies. From participant 43's (ET, PE) example, there is a danger in training junior and younger professionals to operate the machine in an instructional manner where they only learn which buttons to press rather than the meaning behind the different steps and processes.

Hence these examples highlight the importance of educating professionals in the CE and PE industries about understanding technology use in the digital age. While technology may be able to bring about tangible benefits and lead to greater efficiency in work processes, if we only emphasise on learning to operate the various technology or making use of the results and analyses that technology provides us, we run the risk of relying completely on technology and not honing the basic engineering fundamentals and skills which, as we discussed in chapter 3.1A, are crucial to acquiring mastery in the digital age. Another reason why it is important to recognise the skills and competencies that may be neglected due to automation and technologies is because these skills and competencies must still be honed and developed in the case of equipment malfunction or when the technology breaks down. Below is an example provided by participant 31 (ECT, PE), where he discusses the value of his engineering and analytical skills in spite of the availability of technology:

*There were times, when, when, when we had to do extraction of the pumps, for e.g. there's failures. so we had to, um, make an educated guess, why a certain equipment failed. so that was when my engineering skills came out. but it wasn't really engineering skills, more a case of analytical skills, to analyse the equipment. hmm, maybe this is failing because of a certain, because of this. **so there might be 1001 signals saying it's failing, it's just a bunch of data and we have to interpret that data to actually decide what's what's going on.** so finding the root cause of the failure. so, that was the engineering side of things. (Participant 31, ECT, PE)*

Participant 43's (ECT, PE) example highlights that even with the availability of technology and its ability to perform certain tasks and processes, technology is not always reliable and sometimes even inaccurate. Hence one must ensure that they continue to possess the skills to perform the tasks that have been automated or digitalised in the event of equipment malfunction or technology breaking down.

### **Understanding impact is also understanding where human skills and capabilities matter even more**

This however does not imply that the need to be aware of the skills and competencies affected by technology is only applicable to instances when technology breaks down. Afterall, mastery in the digital age involves not just preserving the skills that technology has obscured or made redundant but also looking at the new and additional skills that one should add to their repertoire given that technology is performing certain tasks on your behalf. With technology taking over certain tasks on your behalf also means that we can focus more on the human skills and capabilities - existing, new and additional – that make us better at what we do. This can be seen in participant 17's (ET, CE) examples below:

**... because the computer is doing all the analytical part for you, then where your skill becomes really valuable is how you can communicate this information to the stakeholders. right. so, communication, I think it's very important. uh. obviously, uh data analytics, understanding how these data can be interpreted in the best way, ok. uh and of course, you have to have, systems are becoming very mobile, like everybody can basically use the phone and use the application and, and basically get the information from so, uh, basic understanding of how to use a computer or how to use your, you're the app is important, um. but basically, that's it. ok. how you communicate, how you interpret the data, and how you use the tools that you have. Right. (Participant 17, ET, CE)**

**If all the technical parts are done for you by the system, how do you sell or how do you communicate the value of these things? and how do you look for new opportunities, ok? the computer is not going to do that for you, ok. you have to be very knowledgeable on what you are providing, on the consultancy that you are giving, so when you sit down in a meeting with your customers, you can explain what the computer did for you. right. or what is automated for you. so yes, it is very important that you have, we never were in this kind of industry, you don't have to be a technical expert, we have technical experts. so we have PhDs in chemistry, ok, that understand how the formula works to do this particular reaction, right. and, they understand how the equipment was manufactured, and the process of the thinking of the equipment, so you have your very technical people behind you, ok, but you need to have a very good understanding of how it works, ok. so you can communicate the value to your customers. (Participant 17, ET, CE)**

Participant 17's (ET, CE) examples show the importance of looking at how one can expand their repertoire of skills in the digital age. Even as much emphasis has been placed on picking up digital skills and learning how to operate the various machinery, it is important to note that in the age of digital transformation, technology and digital skills have almost become presupposed and viewed as fundamental skills which everyone is expected to possess. When viewed in the context of mastery, this means that professionals in the CE and PE industries must take into account that it is not just sufficient to focus on picking up digital skills, but it is crucial to look at how they can make use of the technologies to deliver greater value and better results in their work. As seen in participant 17's (ET, CE) example, with automation and technology at his disposal, he is expected to be a better communicator, to understand his clients' needs at a deeper level and to be more competent at his job overall.

Overall, this section has shown that developing mastery in the digital age first and foremost requires a deeper understanding of technology and its impact on human competencies and capabilities. This involves not just being aware of the tangible benefits that a certain technology can bring such as making a certain process error free but specifically knowing the tasks that the technology performs on behalf of the worker and the fact that they will have less opportunities to hone these skills. At the same time, developing mastery in the digital age also underscores the fact that professionals must examine which additional skills they should pick up to deliver better results now that technology has taken over some of their tasks. With the availability of technology, how would the expectations of their superiors or the clients and professionals change? Understanding technology's impact on human competencies and capabilities is essential as it brings our attention back to the skills that have been affected by technology, in terms of how they have been obscured, rendered redundant or become more sought after. No matter how these skills have been impacted, it is critical to discern whether or not these skills are important and essential to developing mastery in the digital age and whether they work towards continually honing these skills in one's career.

#### 4.1B Design to preserve/eliminate and amplify/reduce embodied practice

*Two students sit behind the computer while the other two walk around the installation. On the computer is a representation of the system but, as I described last week as well, with more details and visuals. The students in the control room ask something to those in the field. They don't understand the answer they get yet still base their actions on this. The lecturer points at the importance of always confirming with the field what you think you've heard if there's any confusion, and again before you take an action: "You can't see what's happening out there so you have to trust them". Confirming, even a few times if necessary, is a way to minimize the risk of having missed out on something. "Field and panel, we always have to help each other". Because of the above the students had closed one of the valves too quickly, i.e. not incrementally as was needed for this particular process. (Fieldnotes, Pilot Plant, 5 Nov 2019)*

The previous section discussed the importance of understanding technology's impact on human competencies and capabilities and how it affects the pursuit of mastery in the digital age. Whenever technology performs certain tasks on behalf of individuals, such as doing lab samples, comparing different data points or projecting predictions, it also implies that there are less opportunities for one to perform these tasks and hone these specific skills. As participant 14 (MCT, CE) puts it, the over-emphasis on using and learning about sophisticated tools and technology may cause one to forget their engineering basics:

*I mean, I just quote an example, of, for example, WhatsApp, or, you have a lot of, sophisticated tool for, talking to one another and all that, but the basic is, good, communication, clear language and all that. So, in that sense, you must always review it from that angle, because, from a manufacturing plant perspective, you need to get your engineering, your math, and your chemistry correct. Then, you may have, then you use your sophisticated tools to deliver the results. So, as the tools become more complicated, then we must remember that, always to go back to basics. Like the, ask the why, and things like that. Why, why this one doesn't work, why why why and why. And, so that would, that is where all your basic knowledge would come in. So, sometimes as the tools become more complicated, we are so involved in, using the complicated tools, but we forget our basic. We forget the basic chemistry. So, this is the worst, thing that can happen, because, no matter how, sophisticated the tool is, you cannot, or probably should not replace, a good engineering judgement, or math, or basic chemistry. (Participant 14, MCT, CE)*

While these skills may be perceived as insignificant or even unnecessary, they remain integral to one's engineering and technical foundations that remain indispensable to professionals working in the CE and PE industries.

Therefore, technology potentially has an impact on human competencies and capabilities, and this may be detrimental towards developing mastery. At the same time, it is important to not view all uses of technology as a potential threat to human competencies and capabilities. After all, depending on the technology, and especially on how we use and relate to them, these technologies will change our embodied understanding of work practices (Ihde, 1990). It is thus important, we argue in this section, to move beyond looking at the capabilities of new technologies and to, instead, develop an awareness of how they impinge on skills and mastery. Specifically, we focus on developing an awareness of the impact of technology on embodied and tacit skills. We argue for this point because digital technology is, in the context of manufacturing, understood primarily in terms of the digitalisation of physical practice, such as robots taking over manual labour or smart sensors allowing engineers to work remotely. As such, digital technology 'does' something to our deep, fundamental skills which are to a large extent tacit and embodied.

### Two inter-twined tensions: eliminate/preserve and reduce/amplify

Below, we look at two different tensions via which we can understand this impact of technology: elimination/preservation and reduction/amplification of embodied skills. Where elimination refers to technology making a specific embodied skill completely redundant, preservation highlights the conscious choice to retain these skills because they are critical to a professional's knowledge and, thus, to developing mastery. The reduction/amplification tension hints at the idea that the introduction of a tool reduces certain aspects of our embodied engagement with the work environment while amplifying other parts. For instance, as illustrated by Sergeeva's et al. (2020) study on surgeons working with robots, the surgeons' vision is amplified when operating via the robot while some other senses are employed to a lesser extent (e.g., feeling the warmth of bodily tissue). As mentioned, these two tensions help us become more aware of the potential impact of technology on human capabilities and help make a more informed decision on whether this is deemed beneficial or detrimental to mastery.

It is important to note here that such changes are intertwined, and can mean different things at the same time, e.g., technology can eliminate certain parts of embodied mastery while amplifying other parts at the same time. This can be observed in participant 17's (ET, CE) earlier example. The task of comparing across data points and providing predictions is now performed by technology, eliminating the need for individuals to perform the task. Yet, individuals also get to access a deeper level of knowledge and understanding about their work processes in almost a fraction of the time that they would otherwise not be able to achieve on their own, therefore potentially amplifying their embodied understanding of the chemical refinery:

*So basically, you have all these analysis being done and then what automation is giving you now is that it's comparing 2 trends, oh, 3 months ago you had the same situation and this will happen in the system, **you can visualise things faster. so you can be faster for making recommendations on time, being more opportunistic** and then, second, you have more time to go and talk to your customers to understand more from their side. (Participant 17, ET, CE)*

In addition, participation 01's (Student, CE) example below also demonstrates these intertwined tensions in how smart sensors in chemical plants have helped the engineers do their work from a safer, remote location:

*It's just that now ... instead of just lightbulbs lighting in 3 different, the traffic light colours, now it's actually a digital dashboard **where you can actually see things with data points and like how fast the flow rate is, what's the temperature, things like that.** Ermm using AI, probably instead of having perhaps 3 chemical engineers at the dashboard you can reduce it to just 1. **Because if let's say there is a flow issue, ermm AI will automatically detect and probably just open up the pipes for example and resolve the issue on its own. The technician just needs to know ... the things that will be logged into the system, and later check the issue behind why the pipes were open and after that whether it is resolved or not.** So maybe AI could do this like I don't know 3 times for a designated issue and if the 3rd time the issue is still not resolved then the technicians step in. (Participant 01, Student, CE)*

The trade-offs identified by participant 01 (Student, CE) were also echoed by participant 84 (ET, Other Stakeholder):

*So, it's a bit of a trade-off I would say. Bound to trade off in some of the new technology. Nobody does filing today, last time we used to use a U-channel. 2mm height, U- channel block, file for one week, until become flat. That was the kind of training. Today we don't do that. They try to tell you, why waste the time? Just use the machine to sand it down. But they don't understand a lot of the skills involved, you know? Like the aeroplane industry, the sheet metal work. We used to get a strip of metal, get a pin hammer, knock,*

*knock, knock, and it can form a curve. And this is used in airplanes, you know why? In airplanes, sheet metal, aluminium sheet, when they think it's distorted, you must know where to knock to bend it back. So these are techniques. But today they don't do that. So you still need the old technology. So there's a lot of things changing. But then, there's also good things, let's put it that way. The 3D printer. I just put in and walk away, tomorrow I can collect my part. I don't learn anything. Correct? So digitalisation is advantageous, but it also involves dropping some of the old skills.*  
(Participant 84, ET, Other Stakeholder)

With AI, issues can immediately be detected and different details and information are also immediately available to the engineer at once. However, this also means that the task of going down to the plant to check the pipes physically is being done less often and the sensory, embodied skills that this requires will be used increasingly less. Therefore, the two examples demonstrate how technology can both eliminate and amplify different competencies at the same time.

### **Tackling trade-offs and tensions: deliberate intention, structured framework, and emphasizing core competencies**

It is critical to examine how we can make use of technology in a way that prevents a complete elimination of core competencies, use of embodied understanding and skills given that they are integral to developing mastery. It is important to remark here that this is not a matter of doing what is technologically *possible* but, on the contrary, understanding what is technologically *desirable*. Previous research, for instance, has highlighted the importance of very mundane tasks such as monitoring work (Luff & Heath, 2019; Willems, 2018) in enabling and sustaining the skilful performance of professionals.

In light of the above, we asked our interviewees what some of the measures are that we can implement to ensure that these technologies are used in a way where core skills and competencies can be amplified but preserved at the same time. To which, participant 22 (ET, CE) shares the following:

***Yeah really it's about how you structure your processes, work process and also deliberately creating. So you need to of course, recognise this and emphasise this to the team that this is important. So in your engagement, in your coaching session with the individuals you must point out, you must make sure you let him know that this is important and this is what you want him to do. And then create the opportunity or the deliberate framework to show them what they are expected to do, what is expected of you from the engagement, what kind of outcome is expected of you. So make it a bit specific. I suppose through this kind of more structured way of working, after a while that would help people to learn a certain thing.***  
(Participant 22, ET, CE)

***We have to automate, to digitalise, to use AI to help us but I would say that, maybe I am a bit old school. I always ask my engineers, have you seen this, have you seen that. Have you gone and see you know? So, to me the kind of understanding and having a certain framework and structure in recognising the knowledge and competency, for a certain type of job is important and this could change from time to time when we progress into different eras. It will definitely change. So, when we, looking at this framework, we need to understand that and need to you know, update ourselves as well, the framework. So that it will always stay relevant and optimum to make full use of the time for the very scarce resource.*** (Participant 22, ET, CE)

Participant 22's (ET, CE) response highlights 3 salient things to take note of when it comes to incorporating technology into work processes - being deliberate and intentional, having a structure and framework, and emphasising the importance of core competencies. When training the junior, younger professionals, he is intentional and deliberate in designing the work

processes rather than merely being concerned about getting different tasks done. Consequently, this translates into him designing a specific structure and framework for the work processes. In addition, he also makes sure to emphasise to his colleagues the importance of certain core skills and competencies and that even though they are using technology to perform a certain task, they are still expected to possess certain competencies and skills. This is revealed in the way participant 22 (ET, CE) would ask his engineers “*have you seen this, have you seen that?*”, to ensure that his colleagues are not just mindlessly operating the different equipment but are engaging with the different parts of their work and actively honing important engineering skills and competencies.

However, participant 22's (ET, CE) approach to using technology and being intentional about honing one's engineering skills and competencies when using technology is not widely practised within the CE and PE industries. Instead, as participant 15's (MCT, CE) example below will show, there is a lack of awareness on how technology changes work practices and, thus, on which competencies and skills should be preserved or amplified. Instead, there is a greater emphasis on how technology can make work processes more efficient:

*Because a lot of time, people are too complacent with what they already have. And they fail to look at things from a broader perspective. So in terms of digitalisation, for example I have this equipment. **When it fails, the equipment will just suddenly stop. And it'll give you an error message. Maybe the error message is just 1 red light there. So the equipment stopped and 1 red light error message. Then as an engineer you go there and eh, error message. Then you do not know what's going on.** So for digitalisation, what we do is, let's say for this equipment, the moment it suddenly stops because of some problem, what we do for digitalisation, is we will try to figure out different ways to sense what is going wrong. So, maybe a power trip, maybe overheat. Etc. things like that. So we want to know, we want to really be able to collect the data. And from this equipment and to understand, eh, why did it suddenly stop? So as compared to last time, let's say there's suddenly an error. The poor engineer has to go there and test all the different parts of the equipment to finally find out what is the reason for the problem. **But after the improvement in my current site, what we're trying to aim for is let's say there's an error, immediately I can pinpoint where the problem is. Yeah. So this is 1 of the examples of digitalisation that is going on. And the improvement that we're implementing. Also the automation, it's mainly to reduce human error while also still implementing the previous step I mentioned. So, in case anything goes wrong, we immediately can pinpoint where it went wrong.** (Participant 15, MCT, CE)*

Participant 15's (MCT, CE) example touches on how his company was previously dissatisfied with the functions of the technology that they were working with, where it simply just “*flashed an error message*” but the engineer had no other additional information about the error. Hence, they are looking at updating the function of the technology whereby the technology would be able to immediately tell where the error was. However, as the report has discussed in the previous section, over-emphasis on efficiency and using technology to “*make the job easier*” can hinder the development of core competencies and skills, whereby the individual using the technology does not need to exercise their own critical thinking as much.

### **Designing for effectiveness (and not just efficiencies)**

Apart from adopting participant 22's (ET, CE) earlier approach about being especially intentional when using technology and purposefully designing structures and frameworks around work processes to emphasise certain valuable skills and competencies, our findings have also shown how intentional design of automation systems and technology may be a viable alternative to ensure that core competencies and skills can be preserved and amplified at the same time.

Doing so also means taking a discerning approach towards the design of technology for effectiveness, and not just for efficiency. Here, participant 04 (Student, CE) shares how this approach, which involves the design of technology, will become increasingly important in the future:

*So, one of the things we learn in the safety module in university is that, **when they are designing this kind of automation system or stuff like alarms, alerts, they should be designed in such a way that it's effective.** So, when something goes wrong, it will sound an alarm immediately and that will tell the operator something is wrong whilst also not being activated too frequently because the operator will be desensitised to it. **Oh, just another small issue, no worries. So, I think the design of the system is very important so that the operator knows that it's something, the alarm sounds it means something quite serious, and requires attention.** They shouldn't sound every 5 minutes of the day, then the operator just ignores the alarm, although it may be a big issue waiting to happen. **So, while we implement automation, design is very important, so that it doesn't become counterproductive.** (Participant 04, ET, CE)*

Participant 04's (Student, CE) example shows that technology, when poorly designed, can cause personnel to not just receive wrong information about work processes but also be less inclined to apply their engineering knowledge and skills because of their tendency to simply depend on technology. While participant 04's (Student, CE) example talks about the importance of designing technology in a way to ensure that it does not become counterproductive rather than to preserve and amplify competencies and skills, it raises the importance of the need to examine the design of technology more closely rather than merely being concerned with what types of technology to adopt.

This section has covered two ways in which technology can be preserved and amplified. One way is through being more self-aware and structuring work processes in a way where the importance of competencies and skills continue to be highlighted and emphasised. The other is to design technology in a way that ensures skills are being preserved and amplified at the same time. Even as companies continue to seek out technological solutions to improve work processes, greater efficiency and mistake proofing should not be the only goals that individuals in the CE and PE industries pursue because solely pursuing these can lead to neglect of one's core skills and competencies and is detrimental to one's overall development of mastery. Hence, intentionally structuring work processes and designing technology to ensure that skills and competencies are preserved and amplified helps to safeguard development of skills and competencies which facilitates the pursuit of mastery.

#### 4.1C Use new technologies to experiment/innovate

*Trainer L highlights that students should use PV-tracking, a system that enables students to monitor only key scenarios and have the rest automated. "You have technology to help you and then you don't want to use it. So, if put the system to auto so you have lesser things to monitor. In a process plant you have more things to monitor so you need all of these things to help you do your work". With automation, he was able to monitor multiple screens on multiple processes and respond to them accordingly. But was the only reason that he was able to do so was his 20+ years of experience? How much competency is actually needed to hit this point? If students are indeed trained for such roles, all I've been seeing in the past two hours were 'yes do this' and 'no don't do this'. It does sound like rote learning and process learning and I wonder if we do so, will we just turn the students into mindless droids who are unable to see their work purpose but rather go through motions just because that's how they are trained? (Fieldnotes, Pilot Pant, 19 Nov 2019)*

Section 4.1A had discussed the importance of being aware of the impact of technology on competencies and capabilities and section 4.1B followed up by discussing how we can exploit technology in a way that preserves and amplifies competencies and skills. This section will extend on the preceding one by showing how we can actively experiment with technology to innovate work processes. Moreover, examples from our findings demonstrate that experimenting with technology to innovate work processes can enable the development of mastery, especially when it comes to aspects of mastery that are distributed between different groups of individuals (explored in chapter 3).

As explored in the previous sections, technologies are commonly adopted or used in a way to make work processes more efficient or mistake-proof. However, that was mostly understood through the perspective of assuming that it is the material features or functions of technology that lead to work processes becoming more efficient or effective. While that perspective is indeed true, it is also important to note that technology's impact is shaped by the particular contingent ways in which the technology is designed, configured, and engaged in practice.

As our findings will demonstrate, technologies can be used, configured and engaged in a way to promote higher standards of accountability, improve communication and lead to better training and teaching outcomes. Henceforth, this section will explore various examples of how our interviewees and participants use technology innovatively.

### Using technology to promote higher standards of accountability and professionalism

*Now it's all tracked through Excel, very manual. SAP (Systems Application Processing) does out a portion but it's still not that fool proof. Yes you can do it on excel, because you key in the information, who built the sub assembly, when and how this is built. Who built the sub assembly, and who did the final integration of the robots. Today we have all of these inputted manually. I have the names and information. Today if you ask me, do we know who built it, my answer is yes, you can find it in Excel. Do you know who built the sub assembly? Yes, if you go in clearly, you will see a name printed and printed on the sub assembly. I have names on every sub assembly. (Participant 52, ET, PE)*

Participant 52 (ET, PE) shares how his company promotes a culture of accountability through the use of Excel to track the assembly process of robots, by noting down which part of the robot was assembled by who. While he acknowledges that Excel is not the best platform because manually inputting the information means that it is not 'fool-proof', it still manages to fulfil its intended function. It is noteworthy to mention here that while Excel may be a well-established and rather traditional software it is undeniably used by the company in quite an innovative way. The intention of using technology to track who and when the different parts of the robots were being assembled is to promote a greater sense of accountability and responsibility amongst his staff:

*Participant 52 (ET, PE): Now what is important, in fact I have 1 page, discipline kind of, I call it standard operating procedure, be true, don't hide, because to me the character of each of the staff is important. **Meaning to say if they are not sure about something, they would highlight it. If they did something wrong, they have to share and highlight. Because earlier on we do have some cases whereby they, people hide, hide problems. So we don't want that. So if we hide the problem then that is a problem. We must always surface out the problem so that we can solve it as a team and resolve it.** Earlier on we had a lot of all these issues la. the cables are not tightening properly, losing the electrical connection, when we asked who did it, everybody kept quiet. We do have some sabotage cases here and there. These are more about disciplinary issues. **So moving on, what happens here is that for every sub assembly that they do we have a name on it. I can show you later. Once you have the name, you must be proud of what you are doing and it's not just hiding here and there and trying to hide, go away with the problem.***

*Interviewer: Do you sense that they have that pride that they have already done it?*

*Participant 52 (ET, PE): **Ok so what the company did here is that, I mean on top of that, they have more pride of course, I mean they try to do it perfectly.** And what our boss has introduced is that for any perfect robot produced, the staff will get some incentives. So I guess that's one way that the management can do, you give more monetary reward. Nobody will say no la. so that creates another level of motivation which is another driving factor.*

Tracking the various stages of the sub assembly process has been helpful in promoting accountability and motivation amongst the staff at participant 52's (ET, PE) company. Without a clear system to track who did what, there may be the risk of individuals "hiding" their mistakes or worst still blaming their errors on someone else. Moreover, such a system also encourages professionals to take pride in their work, where given that each sub assembly has a specific individual's name attached to it, they become careful and committed to ensure that they do not easily make mistakes and also actively strive towards building a perfect robot, knowing that their hard work will be rewarded by the company. In sum, technology can be used to promote a specific organisational culture.

Therefore, while it is apparent that the technology used in this example is actually very simple and straightforward, it shows that one can actively use technology to promote certain cultural values, such as taking pride in one's work. In that way, technology can enable the pursuit of higher standards of professionalism, which as we have discussed in section 3.1B is an important component of intra-personal expertise and mastery in the digital age.

### **Use technology to innovate and IKEA-inspired instructional videos to train professionals better**

Another example of how participant 52's (ET, PE) company is innovating with technology is by getting their engineers to create video tutorials, an idea he adapted from the simple-to-follow instructional manuals from IKEA:

*So, I told all the engineers, I mean my team, training must come with videos, I give you an example. I recorded a few, I will give you an example. This is more than 11, maybe about 10-20 minutes. Let me give you an example, the best training aids, best work instructions I have seen so far are from IKEA. Best work instruction. Work instruction, how do you build a cabinet. I believe when you buy something from IKEA, you receive very interesting and clear work instructions.*

*I want the engineers to do it [record the videos themselves]. But of course, they are starting to do it here and I also have my guys to record. So, I have, we bought you know Go-pro. So, when you do something, you talk. Initially when the engineers do it, they take out all the voices, they say it's noisy. I say no la I want to hear you speaking. What's the point of sending me a video without any noise? Why is this important, so when I start to do something, I have the video, I see, I see you get what I mean. **Then I can explain the part number, from 004, I need to use m4 screws to tighten. So, you, because what you see is what I recorded. Once it is done check for alignment. So, you must have that kind of speech, that's what I mean.** So actually, they are going to redo. Now all these videos I can, and then save it by subassembly. If you ask me whether my guys need to refer to all these, yes only initially, after that they all inside already right don't need. Today you see whether they have work instruction with them they don't have. (Participant 52, ET, PE)*

While participant 52 (ET, PE) shares that he was initially inspired by IKEA's instructional videos, the excerpt shows that it is not just the content of the videos that makes it educational and valuable but the way in which his company makes use of technology that makes it a valuable educational experience. What is noteworthy is that participant 52 (ET, PE) insists that

the engineers speak while they are filming themselves assembling the products. This is because having the engineers record themselves explaining the different steps whilst performing the assembly process *actually enhances the embodied engagement of the engineers* who are videoing themselves on the Go-pro. Given that recording an instructional video requires one to have a certain level of familiarity and understanding with the assembly process such that one is able to explain the reason behind the different steps and be able to physically perform the different steps accurately and correctly.

Moreover, participant 52 (ET, PE) also shares that having these instructional videos ensures that the correct way of assembling the product is retained and passed down to following batches of engineers, as he explains further in the extract below:

***So again I go back to the video, it's important. I'm fine with some face to face, I mean we get our engineers to have this physical training with us. But once we finalise the product, video tutorials or some kind of work instruction have to come in, and have to be in place, because that is to retain knowledge. If you don't have those, it cannot be right. For example, if today I want to train you, I will tell you something. We do have cases in this let me share with you, which made me very pissed off. The engineer goes to the technician, whatever he says to this technician is super good, and he writes it down and it becomes almost like a bible. After that engineer will think this is an expert already, and then we expect this guy to go and train. So he trains using his bible, to train. The other person writes it down again and this is something that I cannot accept. So that's the purpose behind the training video, followed by some kind of standard work instruction or whatever in the manual form. If you don't come out with all these, whatever we do is never consistent, based on that. It's based on memory and I can tell you we are still not perfect. There will be some kind of deviation. (Participant 52, ET, PE)***

As participant 52 (ET, PE) shares, passing down knowledge through face-to-face training while valuable also implies that there is no uniform method being passed down. Moreover, it also does not ensure that the accurate and correct method of doing things is being transferred or absorbed both by the individual teaching it or the student teaching it. He also notes that teaching and passing down knowledge based on one's sheer memory is never completely reliable. Therefore, even though the staff may only refer to the instructional videos at the initial stages of learning, these instructional videos are still extremely valuable as they ensure that knowledge that is passed down is always consistent and accurate.

Earlier on in section 3.3B, we discussed the importance of observational learning and how seniors and older colleagues who commonly possess a higher degree of embodied knowledge of manual processes are able to pass knowledge down to their junior, younger colleagues through demonstration. This kind of observational learning is extremely valuable and something that manuals often do not provide. However, it must also be acknowledged that no matter how experienced or knowledgeable one is, one cannot guarantee that the knowledge which they pass down is completely accurate and comprehensive. Therefore, as participant 52's (ET, PE) example shows, instructional videos can serve as a complement to observational learning and further improve the education and training process in the CE and PE industries.

### **Use technology to improve communication and ownership**

The need to have strong communication skills was consistently mentioned amongst our interviewees and participants when asked what were the essential attributes that a master engineer or technician in the CE and PE industries must possess. As participant 09 (MCT, CE) puts it:

*Communication skills are very, very, very important in this line of work. I believe it applies to other kinds of jobs as well but in this job in particular, you are interfacing with people from a lot of different crafts. Whether it is machinery, whether it is instrumentation, we are dealing with so many different types of people right. They are of different backgrounds. And they are of different expertise. In this case I think communication, being able to articulate what we have to say like, for example, identifying what the problem is, how you are going to bring this to the table, to present this to the management, to present it to the different crafts, you can be as technical as possible, but can people understand? So, it's really about how you articulate it right. And I think that is the very important key area. (Participant 09, MCT, CE)*

The communication skills that participant 09 (MCT, CE) alludes to paints the picture of someone who is articulate, clear and emotionally intelligent. Meanwhile, participant 23 (Retired, CE) who has retired from field engineering, portrays a slightly different idea about what it means to be a good communicator:

*Chain of command is very important as well. Especially when you have problems on the rig, right, your boss ah, needs to know everything that is going on the rig. Every 15 minutes, you have to report, report, report, tell him, I'm doing this. ok, next 3 steps, I'm doing this, ok. I will report to you after the first step. then after the first step, you know step 1 doesn't work. going into step 2, step 3. (Participant 23, Retired, CE)*

Unlike the previous example provided by participant 09 (MCT, CE), participant 23's (Retired, CE) illustration of being a good communicator seems to be one that focuses more on informing and updating his boss of his work processes so that his boss is aware of what is happening on the oil rig. Technology may not always enable one to be a better communicator in terms of being more articulate or emotionally intelligent, but participant 52's (ET, PE) example below will show that technology when used effectively can allow accurate information to be conveyed and communicated to relevant individuals without having to verbally converse and share information with people:

*Interviewer: I wanted to ask you about the tv screen that we saw this morning [on the manufacturing floor], who prepared all the information?*

*Participant 52 (ET, PE): My production manager does it daily. We initially wanted to use MES (Manufacturing Execution System) but unfortunately, we have not implemented it yet, so we put it on hold 1st. So, I use that tv, because you don't want to talk about something without a visual illustration. Human beings are like that if I show you a picture, you can absorb faster. I can tell you, let's use m4 to screw, but if I show you a picture - m4 here, an arrow, you will notice it. I have the information in English and Chinese because I have guys from China. So, by doing that, I can look beyond and see other things, and do other things. That's how we grow. I cannot be wah zooming into something specifically, I don't micromanage, there is no need to, I have my 2 IC, my 2nd in charge, to manage the production line and I'm sure that he can manage that. **I just need to oversee some of the key objectives, math, function, enough already. If not, we can't roll.***

*Interviewer: I think that works very well because I can overhear them talk about what their target is for the day like how many units and I think it's because there's information that remind them.*

*Participant 52 (ET, PE): We also text them. So we have Whatsapp, I can share with you. We have things like this, they get a copy of this, they have it, **I mean it's just 1 page and then they can see this is what they do, my name, who do e-tray, who do how many units, this is like a daily target. We put in the quantity, DP you do this one 2, that one I do 3, we based on the calculation, that one needs about 3 hour, that one needs about 4 hour. I can't tell you to go and make this one 10, this one is 3 hours long. So we set some reasonable targets. This is how we do it. Without***

***all these, you don't know what your target is. You just act blur I don't know, go there do that, I don't know how to manage that. So you have this and then you can go to the pc there, scroll up and down using that wireless keyboard. All these are newly implemented. So I don't waste all these facilities or resources that I have.***

As participant 52's (ET, PE) example demonstrates, having a TV screen displaying each individual's tasks and daily targets has been extremely helpful because now everyone has access to the same information and one can no longer use the excuse that the information was not provided to them. Moreover, using the television also allows one to include visual information which is extremely helpful in a manufacturing setting, where mere verbal instruction can sometimes be challenging to understand. Nonetheless, the TV screen has been most instrumental in allowing individuals to use the time that would have otherwise been spent on going to each individual to communicate the information to focus on more pressing matters such as overseeing key objectives instead.

As we have discussed throughout the course of our report, the CE and PE industries are interconnected and multi-disciplinary in nature and involve professionals from many different backgrounds and professions. Moreover, mastery is also becoming increasingly distributed between different individuals and groups in the CE and PE industries. Therefore, the ability to communicate effectively from people of various backgrounds and professions is an extremely valuable skill in the CE and PE industries today. While soft skills such as the ability to communicate effectively must continue to be emphasised and taught, it is also essential to identify areas where technology can be used to accelerate the information sharing process. Rather than going around to pass on information to different individuals verbally, technology can help professionals in the CE and PE industries to make use of their time more productively.

The examples we have provided in this section have sought to show the potential of technology to improve current work processes and inculcate certain values that are critical to developing mastery in the digital age. As the examples have demonstrated, our capacity to innovate with technology should not be limited to the material features or functions of technology. Instead, our way of engaging and using technology can inculcate values and outcomes beyond the technical functions they perform. Thus, technology should be used in innovative ways to develop qualities of mastery in the digital age.

#### 4.2 **Understand diverse work environments (plants, products, processes, and increasingly places)**

Our previous section covered the need to be aware of technology's impact on human competencies and capabilities and how we can use technology to develop mastery in the digital age. This section proceeds to explore the concept of mastery across diverse work environments and how digitalisation has affected the development of mastery in terms of one's understanding of their work environments.

Work environments refer to the plants and factories that CE and PE professionals work in, the products they have to design, develop and/or build, as well as the processes that they have to design and run to produce the products within the plants. Due to digitalisation, the work environment as a 'place' becomes especially prevalent, given that the workplace of a technician or engineer may be far removed from the physical plant or factory floor.

We focus on the relationships between mastery and work environments here for two reasons. As was apparent in our data, in CE and PE industries the specific work environments of companies can be very specialized. Plants, processes, and products are likely to have been

customized, improvised, and honed over multiple customers' needs and over years and even decades. Therefore, firstly, there tends to be a large gap between what is - and, indeed, what *can* be - learned in school and what happens in the workplace. Secondly, and as a direct consequence, the work environments of different companies can be extremely diverse, making it more challenging for professionals to employ their expertise across different workplaces.

Physical work environments and processes in both the CE and PE industries can be so diverse, unique and complex, that even if companies are in the same industry, certain work processes may differ:

*Whatever you learn in school, your takeaway will mainly be the way you analyse things and basic knowledge on – how do I mean, basic theory. **Because whenever you go to a new company, there are trade secrets. There are formulae, there are processes. All these you have to relearn.*** (Participant 08, MCT, CE)

Participant 08 (MCT, CE) response highlights the fact that even for companies within the same industry who may be manufacturing similar products, each company will always have their own distinct work process. In other words, work environments can have similarities but vary widely most of the time. This was also observed during site visits. For instance, the work processes at *Cub Cleaner* involve significant use of technology involving teaching aids, such as step-by-step videos and instructions on TV screens with audio explanations and “*moveable rectangular tables that operators could easily move around to*” (Fieldnotes, *Cub Cleaner*, 23 December 2020).

On the other hand, for *Box Builder*, a company mainly involved in the mass production of high-quality products based on specifications made by customers, work processes follow the KAIZEN<sup>7</sup> approach on the production floor. Therefore, work processes are more manual in nature where we witness the presence of “neatly arranged clipboards clearly stating the job flow” and paper copies of instruction manuals for each technician (Fieldnotes, *Box Builder*, 2 Dec 2020).

In fact, the operating procedures implemented at *Box Builder* are more stringent as compared to *Cub Cleaner*. A similar experience was seen in the CE industry, with an intern reflecting on how his internship experience at a company was very different from what he had learnt at school:

*It's different. For me it's really different. I don't really do anything that I did in poly at my workplace. Everything is new. So, I don't know what to say...I didn't even work in the plant. Mine is a lab... I think I would learn more from lab modules in poly rather than the (pilot plant), I didn't apply anything that I learnt from the pilot plant to my workplace.* (Participant 65, Intern, CE)

This shows the wide diversity of manufacturing work. It implies that the ability to apply one's expertise in different work environments constitutes a key aspect of mastery. As an industry expert of a large CE company mentioned during a focus group: “*When someone with 20 years of experience in a particular company starts working in a different company, their past 20 years cannot be directly applied and one's level of experience is level of expertise and familiarity of the processes at the new company is almost comparable to a fresh graduate.*”

The importance of understanding a diversity of plants, products, and processes has become more acute. At one end, there is a trend of industries becoming increasingly specialised as work environments become increasingly complex. At the other end, new innovations in

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<sup>7</sup> A Japanese business philosophy approach characterised by the goal to continuously improve work operations and processes.

products and processes, and new plants accelerated by digital transformation, means there is a parallel trend of work environments becoming increasingly diverse. These could even be outright different from prevailing plants and processes. Participant 18 (ET, CE), an experienced professional in the CE industry, shares that there is a significant distinction between 'old' and 'new' plants in the CE industry. Old plants contain inherited factors, whereas newer plants that are built from scratch, have an "all clean approach" where interfaces, platforms, systems can be synchronized so it is all compatible with each other. Therefore, professionals working in old and new plants execute very different work processes and operate different types of work equipment, which complicates the process of professionals being able to transfer their skills and expertise between different plants.

### Emerging importance of place

Another way in which digital transformation has affected the attainment of mastery in terms of one's work environment is the increasing prevalence of control rooms in the CE industry where there are fewer people working in the plant. Therefore, digital transformation has led to the plant and control room becoming increasingly separated from each other, where professionals, especially engineers, experience fewer and fewer opportunities to work in the plant. Hence, this has impeded professionals from developing a deep embodied understanding of the plant where they do not get to develop basic skills such as walking and feeling the ground or navigating physical workspaces and machines.

In light of the above, we find mastery in terms of developing a comprehensive understanding of workplace environments and the ability to transfer one's skills across different work environments increasingly essential in the digital age. In the following sections we explain what it means to understand your work environment, how this understanding can be developed and, finally, how and to what extent this understanding is transferable to different work environments.

### 4.2A Importance of feeling the ground

*It's like what he said the day before, today he will be working on the electronic components of the cleaning module and it is fascinating to watch him work. His entire table is now filled with bits of wires, sleeves or connectors, motor boards? It's unlike what it was like yesterday when he was busy with coding on his laptop. I think it is fascinating how his work requires different skill sets and now, it's like watching the hands-on Intern S as opposed to coder/programmer Intern S for the past few days. (Fieldnotes, Box Builder, 8 Dec 2020)*

A common idea frequently being brought up by our interviewees is that of "getting one's hands dirty". This can also be seen in the observations above: the coder is now being hands-on, and even though students are working in the confinements of the laboratory, the *Pilot Plant* and, by extension, their future workplace, is continuously there as a reminder of where work will get done. This idea of getting one's hands dirty can be understood as the physical and laborious nature of the engineering profession. For those in the CE industry, this means going to the plant, refinery or oil rig to check that the equipment and chemical processes are running smoothly. Meanwhile, for the PE industry this means having to physically manufacture and assemble products by themselves. These all continue to be a big part of engineering work, despite the digital transformation of workplaces:

*Another important skill engineers should have is being able to conduct equipment inspection, how do you inspect pressure equipment, how do you inspect piping. There is a specific focus, international codes and standards plus company, technical documents, technical requirements. So, they have to kind of go through and understand*

those requirements and be able to practice them. Yeah, so that is one part. **So, they need to be equipped with the kind of ability to grasp this kind of learning and then after that of course is the physical inspection part, that is really a lot of going to the field and getting your hands dirty.** (Participant 22, ET, CE)

But you **will still have to use or get your hands dirty.** You could be a salesperson, for example, but you still have **to get your hands dirty** in assembling and dismantling robots, for example, as well. So here, even though we clearly define our roles, in a sense, we are not encapsulated within only that role. We still have to do things knowing that as a small company, we have to do things to survive, in a sense. So, if I am even a team lead in a mechanical area, I will still have to **get my hands dirty** and work on a certain system in the project. If I'm a software lead, for example, I might still have to work very closely with the mechanical department team, and also **get my hands dirty** into actually doing physical items as well. (Participant 33, ECT, PE)

Digital transformation, however, has led to an increasing emphasis on the digital aspect, especially with regard to automation and Internet of Things (IoT) in the CE industry and the digitalisation of manufacturing processes in the PE industry. Nonetheless, being skilled in the physical and manual aspect of the job remains an important aspect of mastery. Therefore, this section of the report focuses on the skills and competencies that enable one to continue to perform the physical and manual aspects of one's work while those same work processes are being digitalized. Given that "feeling the ground" means different things in different work contexts, we discuss our findings on the two industries separately.

### Meaning behind feeling the ground in CE industry

The term "ground" was frequently mentioned by many of our interviewees from the CE industry to describe the physical plant:

*I'm saying this from an engineer's perspective. um. from, from an operator or technician's perspective, **they are on the ground all the time.** so, eventually [what happens] from point a to point b [in the plant], becomes a part of their core. so, they are super experienced. but for engineers like us, **we are not always on the ground,** we are always in the control centre, we are thinking. (Participant 07, ECT, CE)*

Meanwhile, the idea of "having a feel" was a phrase used by one of the educators at our fieldwork observations when he was addressing his students at the plant:

*The lecturer says: "Today is for you to go out there and **get a feel of the plant**". What he means with this 'feel' is perhaps best understood as a mix of getting to know the plant and also developing an actual, intuitional and bodily feel for it. (Fieldnotes, Pilot Plant, 12 Nov 2019)*

Even though this term is predominantly used in the CE industry, when combined together, we feel that the phrase "having a feel for the ground" best encapsulates what it means to develop an embodied, intuitional, bodily understanding of work that is more physical and manual in nature.

### Digital transformation risks: fewer and fewer professionals with a 'feel of the ground'

As mentioned, the current discourse surrounding digital transformation and the 4IR have placed a significant emphasis on how there will be increasingly fewer engineers and technicians in the plant in the future because one is able to receive required information and control most of the plant processes from the control room. This was also brought up by our interviewee, participant 07 (ECT, CE) and participant 22 (ET, CE), both professionals in the CE industry:

Technology is always an evolving process. So, um, previously um, how people would control a plant, someone would actually have to go down to the plant itself to turn a knob, to turn a bulb, and they have to see the gauge pressure, see the, the gauge, the needle on the gauge, this is enough, I'm going to adjust it a bit more, and then they will go. And they have to always stay within the area, just in case anything happens. That was, that's old, olden days. Then, they moved on to pneumatic control, where instead of having to go to each and every valve to control it, there will be a centralised area where you can control the valve using pneumatic sequence. So, you just turn this valve, and then like 20m away, the valve will turn. So that's pneumatic control. And then, they moved on to that, to electrical and like what you say, digital technology (...) Essentially, you don't have to go down on site to turn a valve anymore. I just sit in the comfort of my own office, I can just click a button, the valve will open. and somewhere, I don't know, the other side of this campus, one little valve will open. So that is how it has improved. It has improved our response time, our reaction time, and it also significantly reduces our need for additional, a lot of manpower, wasted man hours actually. Because, when you have one guy patrolling a one-hectare area of, sorry, really large area of plant, you can't expect him to run to that valve straight away. it's not humanly possible. But if I have an overview of the plant and I see all right, this is giving me an issue, click, done. straight away. (Participant 07, ECT, CE)

**I foresee, in future, I am not sending a technician to the site to take measurements of that steel anymore.** In the future, it could be a probe that has been installed on site and sent to me via wireless signal, into my computer and the engineer just needs to sit behind the computer and look at the reading (...) So in times to come, imagining an engineer were to be recruited to do the job and the 1st day he works in front of a computer and starts to analyse the result and all that, **without knowing what is actually happening on the site.** How the pressure vessel is being designed, what is the expectation of the stress and all that. 10 years down the road, 20 years down the road, they probably spend 80, 90% of the time in front of the computer and maybe 10% of the time in the field, maybe, I don't know. (Participant 22, ET, CE)

Plants are increasingly being controlled by the control plant and the CE industry is slowly moving towards having less manpower patrolling and walking the field. This creates a risk that fewer and fewer professionals will have a feel of what is on the ground in the plants and how the basic processes run. That is why participant 22 (ET, CE) still makes it a point to go down to the plant physically to inspect it himself where he reasons that even though:

*I spend a lot of time in meetings nowadays. I try to also spend time walking the field. For example, before this meeting I actually went to a plant and walked up to a 6 storey almost high structure, looked at some equipment before I came back, before I rushed back to this meeting.... **Very, very important is really to feel the ground, to go and see, go and see the physical stuff, go and see the physical activities, what is happening there.** (Participant 22, ET, CE)*

### Why it is important to 'walk the ground' (CE industry perspective)

The remainder of this section will discuss the reasons why it is still important to have a feel for the ground even in the age of digital transformation in the CE and PE industries.

#### Sensing deviations

Firstly, walking the ground is important due to the possibility of deviations occurring. As our interviewees shared, information provided by technology is not always reliable. The separation between the control room and the plant implies that deviations can only be accurately identified when one is walking the field. This was demonstrated during our field observations at a polytechnic:

*When we were discussing with one of the instructors at a practical session, the instructor mentioned that : **the field operators were, are, and will be crucial to any plant, even in the context of what digital technologies promise. “You can’t rely on just the technology and the panel operators”, he mentions. “The [people working in the] field are the 2nd pair of eyes for the [people working in the] panel ; they need each other”.** He goes on recollecting the plants where he has worked and remembers there is always someone physically in the plant, walking around and continuously checking for deviations. **“It is in the field where deviations will be noticed, and not in the control room. These must be seen. Or heard, or smelled.” The move from field to panel is a process that can take up to 10 years. A technician first needs to understand the field really well before he can go work in the control room.”***  
(Fieldnotes, Pilot Plant, 05 Nov 2019)

While it may be possible to control most of the work processes occurring in the plant from a control room, the extract above highlights that the ability to control is in fact very different from the ability to access information, especially important information about the plant concerning deviations. As demonstrated by the use of the term “second pair of eyes”, the people working in the field have access to information that people working in the control often do not have access to because such information is felt by one’s senses - through sight, smell and hearing. In fact, as the instructor also highlights, technicians first need to understand the field really well before they can work in the control room, suggesting that one must first be sufficiently knowledgeable about the field before they are able to make important decisions that will affect the work processes in the plant.

The extracts below are additional instances that point to how those working in the control room have limited access to information about the plant and depend on plant operators to inform them of the state of the plant:

*The instructor points at the importance of always confirming with the fieldmen what you think you’ve heard if there’s any confusion and before you take an action. You also have to trust them, as they can say yes but do no or vice versa. “You can’t see what’s happening out there so you have to trust them”. Confirming, even a few times if necessary, is a way to minimize the risk of having missed out on something. “Field and panel, we always have to help each other”. (Fieldnotes, Pilot Plant, 05 Nov 2019)*

*For instance, he’s also aware of the fact that some of the students will be working from the control house today; they, being located even further away from the actual process, will only see lines and numerical values from which they have to make sense of what’s going on. (Fieldnotes, Pilot Plant, 04 Feb 2020)*

Lastly, the extract below by participant 02 (Student, CE) demonstrates that on top of having limited access to information from the plant, the information provided by the technology may not always be accurate or reliable due to malfunctioning sensors:

***So, some, let’s say level sensors in your control room can malfunction as well. Let’s say they indicate 50% in the computer screen, but it may not be the case in the actual field itself la. So, some technicians are required to go out and check. So, there’s the thing about the control valve checking as well. You have to do something called a strobe check. It’s just to see whether, when you say your control valve is open 25%, does it actually open at 25%. So, from the control room, it is set to 25%. Then outside in the field, the technician will check whether it’s actually 25% because there’s like a needle on the scale on the valve itself. (Participant 02, Student, CE)***

The possibility of technology malfunctioning implies that mastery in the digital age will continue to constitute physical and sensorial, embodied skills. The opportunities for technical professionals to do so, however, decrease with digitalisation.

### **Making concrete sense of the symbols, diagrams, and visual representation of a plant**

Symbols such as those used in P&ID<sup>8</sup>, which are graphical representations of a process system, do not provide an accurate representation of the physical plant used in the industry. Hence, understanding of the physical plant must be gained from actually going down to experience the plant for themselves rather than depending merely on visual representations:

*The difference between students and the instructors is also apparent here: students still need to look and analyse what is what, the instructor simply 'sees' it; for him, the distinction between the symbol and what it represents doesn't seem to exist anymore, or at least it's not an issue. To complicate things, the instructor also highlights how the symbols on P&ID (piping and instrumentation diagram are just that, symbols: they look very different in reality, and they can also look different per plant. (Fieldnotes, Pilot Plant, 26 Nov 2019)*

*"You have to know what they look like and how they are represented", he says, while comparing some of the physical features with their symbolic representation, or their names with their symbols. Technicians need to know both of these modalities because of the fact that a lot of the process control takes place in a distributed system, i.e. in the plant and in the control room. The instructor tells the students that in the control room they will only have access to the symbolic representation of the plant, reminding them that in the training centre located in school the control room and the plant are co-located but that in reality the distance can be very large; in those instances, panel operators need to do everything via the representations, and this includes knowing what the symbols represent and do. (Fieldnotes, Pilot Plant, 26 Nov 2019)*

The above extract highlights two salient points. Firstly, being able to recognise and tell what the symbols on the P&ID represent requires familiarity and experience. Secondly, the symbols are just symbols, and bear little resemblance to the equipment that they represent in reality. This shows that not only are the symbols difficult to recognise, it is also insufficient to only know what the symbols represent because they look very different in reality. Knowing that those in the control room will mostly only have access to a symbolic representation and that panel operators need to make decisions using symbolic representations, it reinforces the point that a good understanding of symbolic representations is limited, and one needs to complement it with familiarity and knowledge of the physical plant setting and knowing what the symbols represent:

*Another interesting thing that the instructor highlights while he's going from slide to slide to show different symbols and equipment is the problem that digital instruments very often look alike, which is not the case with manually operated instruments: "I am teaching you in this class how to recognize meters or gauges from afar, but with digital equipment you can't do this so easily. You need to see the values on it to know what it measures and what instrument it is". It's thus an example of digitalisation allowing for standardisation but, in the process, reducing some of the more sensible elements of it (e.g. the visual aspect of how an instrument looks and is recognized as such by a technician). (Fieldnotes, Pilot Plant, 26 Nov 2019)*

<sup>8</sup> A piping and instrumentation diagram (P&ID) is a diagram showing the interconnection of process equipment and the instrumentation used to control the chemical process. Symbols are used to make drawings of these processes.

On a related note, it is difficult to distinguish digital instruments and equipment. Unlike meters or gauges that can be recognised from a distance, often, one is only able to tell which digital equipment is which after looking at the values showing what it measures and what instrument it is.

Symbols and visual representations may offer an incomplete and misleading account of what is happening in the plant. Additionally, digital instruments and equipment in the plants are also not easily recognisable. It is through spending time, feeling the ground and familiarizing oneself with the physical plant that enables one to properly understand what the symbols represent and distinguish between different digital equipment. Hence, it would be problematic to be in the control room and only rely on symbolic representations to understand what is going on in the plant without much experience or knowledge of the physical plant itself. This type of more situated understanding of technology is a crucial aspect of mastery, but also something that is usually left out of the conversation on digitalisation.

Here, another example from our fieldwork observations captures the process of a group of students trying to understand the physical plant whilst depending on the symbolic representations:

*Here, they use different techniques to make sense of the piece of equipment in front of them and how to do their line setting. **First, they individually start walking around the installation: some just look while others touch the lines and valves without really doing anything. For instance, they may touch a valve but not open or close it. Perhaps this is just a more tactile way of learning or remembering, as if they're bodily imprinting the abstract map of the machine to make it a bit more concrete and easy to remember or understand.** The students then gather around the neutralizer. **One has the map opened and follows the line with his fingers while the others follow. It reminds me of finding your way on the map when lost, and you usually would put the map on the motor hood.***

***This is not just because of the convenience to support the map onto something as they can be a hassle to hold in your hands, but also can be seen as a way to really (i.e. physically) connect the map/representation and reality/materiality of what you're trying to do. The students need both map and material reality to make sense of the process, and things come together in this instance. It's more of a reciprocal process than a consecutive one: the map by itself is too abstract to understand on its own while the installation by itself is too complex to understand without the simplified representation of the map!** Finally, and actually without much discussion or decisions being made overtly, two students start walking around the installation while the other two read the map and translate which valves have to be opened or closed. (Fieldnotes, Pilot Plant, 05 Nov 2019)*

The extract above highlights the complexity of the physical plant and how a comprehensive understanding of it cannot be derived from the symbolic representations. The act of touching the lines and valves without doing anything in particular is an example of how one needs to process the plant through the sense of touch itself. At the same time, the students also constantly refer to the symbolic representation or the "map" when they are in the plant because the map by its own is too abstract while the physical plant is too complex to understand without the map. Therefore, mastery in the aspect of having a good understanding of the physical plant comes from being familiar with both modalities - the symbolic representation of the plant and the physical plant itself.

### Navigating the rules and social expectations of 'the ground'

Up till this point, we focused on the importance of feeling the ground from a slightly technical perspective, highlighting how being in the plant provides one with deeper information than one has in the control room. We also highlighted the difficulty of understanding the physical plant only through symbolic representations. Yet, the experience of being in the plant is not just technical in nature. It is also constituted in social interactions.

Therefore the third reason why it is important to feel the ground is because the physical plant is a particular work setting, different and unique in and of itself, and characterized by rules and industry practices specific to the plant not found anywhere else. Therefore, one cannot simply gain that kind of understanding of the plant by learning about it theoretically or through symbolic representations, but acculturation comes mainly through experiences gained from being physically in the plant itself. Learning, in that sense, becomes synonymous with working and knowledge is not transferred between minds but it is shared between people engaging in a practice (Nicolini et al., 2003).

In fact, our interviewees and field work participants constantly alluded to the physical plant being an entirely different place, frequently likening it to the military or something that can only be truly understood not by hearing or reading about it but only by being physically there. This sentiment is conveyed in participant 21's (ET, CE) and participant 17's (ET, CE) examples below:

*I mean, there's a bit of a learning curve [when it comes to the plant], there's a lot to learn. Most of the subject matter was familiar but **then it likes going from what you read in the book to actually seeing it in real life right**. Show my kid the picture of a giraffe and then he goes to the zoo and sees an actual giraffe, it's that type of thing, that type of an experience. **And also being offshore and being in operation, I, compared to being in the army, it's, you're outdoors a lot, you wear your uniform, there are strict rules to follow around safety and procedure and you are working in a largely male oriented environment, male dominated. I liken it to being in the army. And I think the army experience helps out.** (Participant 21, ET, CE)*

*Ok, they have to understand how work in the field is done, ok. **it's kind of like very military oriented, you know, like you have to go and sweat in the field so you can go up, and understand from our side that a chemical process in a refinery looks like, I don't know if you had a chance to be there, but a refinery looks like a mini city, all right, and it's very hard to understand the process of it if you are not there.** like a lot of times, even for me, I don't have to be in the field at all, if I don't want to, all right, but if I'm trying to solve a problem that uh, uh a customer has, it's very hard for me to solve it without going to the field and looking at the, the site. ok, so, this pipe goes here, enters into the boiler, and then it gets out of here. you need to go and see it. (Participant 17, ET, CE)*

On the other hand, the plant itself also has its own specific rules and safety practices that apply specifically to the plant itself as seen in the example below:

*I also realised that in this practical, a student tried to bring his laptop to the centrifugal standalone plant. In doing so he was told off by the technical executive that no electronic devices were to be brought past the yellow line. The student wondered to himself why on earth there is such a rule, and the technical executives just said it is industry practice. The student then turned to me to try to incite a response and I said 'perhaps it's like the airplane thing? [where you are not allowed to turn your laptop on during take-off and landing]' (Fieldnotes, Pilot Plant, 14 January 2020)*

As seen from the extract, the student was visibly surprised that such rules were present in the plant and had he not been warned by the technical executive, he would never have realised that there was such a rule. On top of the strict safety standards that must be adhered to, it can be seen that the plant is a place with its own rules and regulations. Hence, it is only through spending time in the physical plant itself where one gradually becomes more familiar with these peculiar rules that may not be applicable anywhere else apart from the plant.

### Why is it important to ‘walk the ground’? (PE industry perspective)

In the PE industry, ‘feeling’ the ground comes in the form of product manufacturing and operation, and their corresponding processes. This may also look like an easy task that anyone is able to do:

*Technician I walked over to where an unclad robot was being assembled and I watched as technician I checked the screws (by touching and looking at it), he then went to get a drill and re-did the screws. (Fieldnotes, Cub Cleaner, 23 December 2020)*

This excerpt from an observation at *Cub Cleaner* describes how technicians identify and troubleshoot problems through the uses of their senses – touch and sight – which can make it seem like they have ‘magic hands’ due to the invisibility of the cumulative experience that formulate the ability to feel the ground. In the PE industry, feeling the ground can be understood as the physical, manual process of product manufacturing that depends significantly on one’s physical and embodied senses. The expertise for this risks being obscured by digitalisation (similar in nature to our CE findings above). As participant 84 (ET, Other Stakeholder) described:

*When I’m using the 3D printer, I just put something in and walk away, tomorrow I will collect my part. I don’t learn anything. (Participant 84, ET, Other Stakeholder)*

Hence, as our findings will show, the physical, manual aspect of the manufacturing process remains important in the PE industry. This is because physically and manually assembling products remains quite prevalent in the PE industry today. This can be seen in participant 52’s (ET, PE) example below:

*Automation is good for repeating tasks, homogenous tasks. You can have some change but for that change to happen you must have that setup time. For example I get a robot, I can programme it in a certain way but if I want to change it then I must reprogramme and reset the parameter to allow it to do this. That is called a setup time. You must be able to judge whether your current volume justifies that. If you ask me for all this robot, my answer now, no. nope, don’t waste time. You can’t do automation because right now I’m only building 2 to 4 units a day, you can’t and it’s a huge investment. (Participant 52, ET, PE)*

### Sharpening the senses is sharpening skills for customisation and quality

As participant 52 (ET, PE) explains, the nature and volume of the company’s production may sometimes not warrant complete automation of processes. There is thus constant customisation and variations arising from different customers, and sometimes even for the same customer (where the changes requested may be frequent too). Therefore it is critical for engineers in the PE industry to possess physical and manual skills that allow them to assemble and manufacture products by themselves.

Remarkably, our interviewees from the PE industry also use the term “*having a feel for...*” when articulating what it means for one to be good at the physical, manual aspects of the manufacturing process. This can be seen in the example below. When asked what sets an

expert and average engineer apart when it comes to manufacturing robots, participant 52 (ET, PE) shared the following:

*For robots it's a bit unique. Men and women also have differences **because it's very heavy. So that's one thing. The other thing is that they cannot be colour blind, you cannot be colour blind and then red and green cannot differentiate, disaster. So, they must be, I think eyesight is important because be able to do and the feel. Cables. When you say they're in but then are fully in, is another question. So this is what I think and they must be very, other than the strength because of heavy screws and so on, they must have a feel of the parts. That's what I think. I mean all these you can't tell, only when they do things because the screw is so small you must be able to pick it up and really tighten. You may think it's tightened but then it is slant and so on. So that kind of 'feel' is a very important skill set. Everybody can do la, I don't think nothing is difficult, all of us can do but whether you have the feel, is a bit different. Over time you are able to do it. Feel la, I mean everybody can do, but whether you have that feel, able to have that good touch assembled, that's another thing. And you must have a good sense of process. To build integrated robots, which one to go first and so on, so that process is actually very important. it's through practice lah, I can't tell. 1st unit you are not so good, 2nd unit better and so on. It's through experience. That's why version 1, a lot of design challenges and so on, then version 2. Version 3 is much better; we have a much better yield now. (Participant 52, ET, PE)***

It is noteworthy that even though participant 52 (ET, PE) is from a start-up manufacturing high-end robots, he emphasises the value of the senses to the continuous improvement of the quality of the robots. He also emphasises the importance of physical qualities such as being physically strong and not being colour blind rather than technical skills. In addition, while participant 52 (ET, PE) mentions that the physical and manual aspect of the manufacturing process is not especially complex or difficult, it is evident that some individuals have a “*better feel*” of the assembly process, and more often that ‘feel’ comes from experience and practise and a good sense of process. Hence, this reinforces the importance of ensuring that engineers in the PE industry are given opportunities to “*feel the ground*” to sharpen their senses so as to hone their physical and manual skills. Especially so when professionals are increasingly being removed from the physical work environment that constitutes this ‘ground’.

Overall, this section has discussed the importance of “*feeling the ground*” in both the CE and PE industries. Even with the growing prevalence of automation and IoT in the CE industry and use of cutting-edge technology in the PE industry, our findings show that it has not completely eliminated the need for engineers to possess the types of physical, embodied understanding found in personally inspecting the plant or personally assembling a product. Moreover, in line with our overarching argument about how mastery in the digital age is invisible in nature, this section has demonstrated that automation, IoT and cutting-edge technology can easily lead one to perceive that that technology has eliminated the need for certain skills and competencies. However, the wealth of information embedded within the plant, the need to complement symbolic representations of the plant with a physical, sensory knowledge and the social, acculturation aspect of working in the plant are not readily visible.

#### 4.2B Having a deep embodied understanding of the ground

*The instructor sends three students into the Pilot Plant to do their line-setting as field operators. Two others remain in the Control Room. The idea for today is to start up the plant and shut it down, and then change roles so both get to practice both sides. The lower screen of the workstation in the Control House shows a map of the plant. It's quite an abstract representation with a lot of lines and numbers. If you press on one of the elements such as a line or column), a pop-up appears giving more information about it. Through this exercise, students get to practice what it means to work in a plant without actually being in a plant. (Fieldnotes, Pilot Plant, 29 Oct 2019)*

Our previous section discussed the importance of feeling the ground, how it constitutes a key aspect of mastery in the digital age, and how it can be challenged by technology. This section aims to build on the previous section by discussing what it means for one to be good at feeling the ground and how one can develop this particular aspect of mastery.

In building on the previous section, this deep embodied understanding of the ground is also distinct from the previous section as it focuses on how deeply one is able to sense deviations, make concrete sense of the symbols, and improve the quality of one's work successfully. The litmus test for this depth is how familiar, thorough, and meticulous one is during the routine and non-routine and the familiar and unfamiliar such as inspection and troubleshooting. Our findings show that this includes one's ability to visualise the entire system, how incisive one's troubleshooting and inspection skills are, one's knowledge of how different parts of the ground fit into the overall system, and who to access when doing all the above.

It is no coincidence that these in fact mirror several of the dimensions of mastery found in chapter 3. Chapter 3 in its entirety is about all the formal and informal interactions needed to run the system smoothly and successfully. It is the *who*. The dimension in this section is about *what* one needs to do to run the system smoothly and successfully. Their overlaps validate what our research found about both dimensions, illuminating how expertise is distributed across each of them, and that the expert in the digital age is one who is able to pull all these multi-faceted elements together in practice.

### Visualizing the plant imaginatively and concretely

During one of our fieldwork observations, we noticed the particular manner in which an instructor taught his students how to anticipate what is happening in the plant even before being there through visualising it using the P&ID:

*The JSA (Job safety assessment) asks several questions regarding which parts of the job run which risks and how these can be mitigated, and it boils down, according to the instructor, to the "What-How-What-How" principle: **Firstly, he tells the students to think of the task at hand and think of in what steps or tasks this is broken down; then, students need to visualize these steps so they have a clear image of how these tasks will be conducted. From this visualization exercise, students can then conclude what potential risks may arise (e.g. the handling of an acid potentially causes skin burn to hands and eyes) and, relatedly, how they can mitigate this (e.g. wearing chemical gloves and glasses). I find the 'visualization' bit quite interesting. It's not just a procedural 'checking off the boxes' but actually requires quite a bit of imagination. Even more so because this exercise is done based on just the P&ID (piping and instrumentation diagram) rather than going out into the plant. The instructor elaborates a bit more about this. The main reason behind today's exercise is to perform line-tracing on a piece of equipment to check which valves have to be closed and opened and check if they are indeed in the right direction. **Students won't be operating anything today, but they will have a first encounter with learning to read their equipment, starting with the P&ID.** The instructor emphasizes during the instructions quite a few times that this is how technicians in plants work: "You first always visualize. This is what technicians do before they go out to a new plant. **They get to know the plant via the P&ID, and only then go physically check it. But they still do this via the P&ID without touching anything. They first look at which valves have to be opened or closed**". After the exercise the instructor adds that technicians and engineers also very often draw a P&ID themselves. They first read the existing one after which they go and inspect it in the plant, just by looking. **They then draw it themselves, both as a way to check whether the P&ID given to them is correct but also, and perhaps even more importantly so, as a way to imprint the plant into their minds. This reading, re-reading, checking what is represented with reality and then writing is a way through which a technician develops the adequate know-how of specific plants.** (Fieldnotes, Pilot Plant, 12 Nov 2019)***

As the fieldnotes demonstrate, visualising a plant contains several important elements and they involve the process of imagination, supported by drawing and reading P&IDs, and finally comparing these symbolic representations of the plant with the physical plant itself.

The first part of visualising the plant involves using one's imagination and having a mental imagery of the plants in one's mind. Moreover, this is done so in a structured and organised manner, specifically through the "What-How-What-How" principle, where one needs to break down the process into different individual tasks and then think about what the possible implications and outcomes are after performing each task. Hence, this requires one to be familiar with the different tasks and processes that one has to perform.

The second part of visualising the plant involves drawing and reading P&IDs. Our previous section discussed that merely depending on symbolic representations such as P&IDs does not provide one with a complete understanding of what is taking place in the plant. Yet, symbolic representations are often the best representations of the plant, therefore it is essential to use tools such as the P&ID to comprehend what is happening in the plant. Moreover, being skilled at using such tools, will allow one to better visualise processes that are taking place in the plant. Those who possess a deep embodied understanding of the ground often are competent at understanding symbolic representations and using tools such as P&ID. In other words, while symbolic representations of workplaces will not provide the most comprehensive account of the plant, they can still be used as a way to visualize and, thus, come closer to the actual manufacturing process.

Finally, the last part of the visualisation process involves using the symbolic representations and one's own P&ID (s) and to check it with the actual processes happening in the plant itself. This reinforces our earlier point that professionals working in the plant must be skilled in both modalities, understanding the plant through symbolic representations and understanding the physical plant itself.

Visualisation goes beyond knowing the process factually: it is an attempt at developing an in-depth feel for the ground, even if that ground is not yet there. This also highlights the multi-faceted and layered nature of mastery, whereby visualising the plant is not just projecting visual images of the plant at random but going through a systematic process to understand the plant at different levels and scales.

### Troubleshooting and inspecting incisively

The next area that shapes one's embodied understanding of the plant is one's competence in inspecting and conducting troubleshooting. As our interviewees have shared with us, tasks and responsibilities in the plant mainly revolve around checking on the condition and state of the different equipment in the plant, to ensure that there are no anomalies and deviations with the information gathered in the control room. Therefore, knowing the plant well or having a deep embodied understanding of it requires one to be thorough and meticulous with their troubleshooting:

*So actually, the main part of the process engineer would be for troubleshooting. So, what most process engineers do will be to monitor, to make sure the plants are operating as expected, as per normal on a regular basis. So, like every hour, every day. And then if anything goes wrong you need to do troubleshooting and most of the time it's not obvious where things are, where the source of error is. So that's where intuition and like all life principles come in useful. So, if let's say we have, we notice there is some leakage, where is the leakage most likely to be. So, both based on experience, can be gained or can be learnt from other more senior people and also based on the stuff that we have learned on paper or both in university or in the company itself. (Participant 04, Student, CE)*

What is pointed out is the quality of incisiveness: the expert knows where in the system something has gone wrong, even when it is not obvious. It is visible to his expertise even when it is invisible visually and invisible to those who are less skilled.

This is reinforced by participants 02 (Student, CE) and 08 (MCT, CE), who also mention what they think are the factors that shapes one's competence in troubleshooting:

***[An ideal engineer] has to be someone who is very committed, I guess. Someone who is ok with always doing the same thing, because from what I heard, technicians do shift jobs, but they are pretty much doing the same thing. Their job there is to like to monitor process parameters which can be quite boring, but it is also an important job. Some character traits that they should have is diligence, I guess. They shouldn't slack off on their work even though it's boring because it is important. Besides that, a chemical engineer maybe they should be quick thinking as well because at times when you discover certain weird happening in the plant which is abnormal, we have to be quick thinking on our feet as to what actions to take afterwards, what happens and also like analyse, do some analytical thinking to like, what is, what causes this behaviour something like that. So that's what I think, the traits that we should have. (Participant 02, Student, CE)***

***Because technicians will – those hard-working ones, they will highlight those critical points. Oh, they found that the oil is low, so what we need to do, or the pressure is low, what we need to do. So, all of the equipment is critical. We have to look at the condition, check the conditions. (Participant 08, MCT, CE)***

As seen in the examples above, this incisiveness is ever present. For example, monitoring the plant can often seem meaningless and unimportant because of its repetitive nature, hence one may be tempted to cut corners, where it seems like nothing is happening most of the time; often, the deviation is not obvious, or the source of error is not immediately identifiable. Therefore, one must be diligent and thorough when inspecting the plant, going beyond the surface to cover every aspect to find abnormalities. This aligns with our overarching argument that mastery in the digital age is invisible in nature because going the extra mile to uncover or identify abnormalities that may not be readily visible is an indicator of having a deep embodied understanding of the plant.

In addition to being able to identify abnormalities, one should also be independent and proactive to devise the possible sources of error and to analyse the reasons behind the abnormalities that occur. Consequently, what enables one to be aware of the possible reasons and factors that contribute to the abnormalities happening in the plant is their knowledge of how different parts of the plant or work environment fit into the overall system. This is also the third factor that shapes one's level of understanding of their workplace.

### **Knowing how different parts fit into the system proactively: the smallest parts can have the largest consequences**

***If the work involves more of the troubleshooting of the product specs, the quality. There's so many things involved around all these problems, which would result in these kinds of problems. For example, just in a plant which is so big, 1 equipment fault can result in off-spec. Yeah. then without knowing the root cause you have to base on whatever data you have, to find this minor problem, solve it. That's the kind of challenge you have. Then we're dealing with a lot of data just to do problem solving. (Participant 08, MCT, CE)***

One must take into account multiple factors during the troubleshooting process and the more one understands the plant, the more they will be aware of the possible data and factors that can contribute to certain errors occurring and lead to them performing more accurate

troubleshooting. This is further confirmed by participant 07 (ECT, CE), who shares his process of understanding the plant below:

*If my job requires me to understand the plant as much as possible, that's what I have to do. I understand the process of taking raw material and converting it into a product. so, for example there is this particular valve. It's called the uh JT valve, Jewel Thompson valve. Essentially what it does is it reduces the pressure of the gas going in. So we will take the gas, maybe like about 10 atmospheric pressure, it goes through this valve, and it can come out maybe 5 atmospheric pressure. It cuts down the pressure. and it's, it's a valve. It's a very simple valve. and there's no loss in temperature. There's no loss in energy. It's just a reduction in pressure (...) **But How does it work? How does this simple mechanism actually reduce pressure just like that? Just by in and out? It's not a huge thing, it can be very small, depending on the pipe size, it can be very small. but how does it work? And that's what I've been spending the past few days trying to understand how this valve works.** (Participant 07, ECT, CE)*

The example above demonstrates what it means to know how different parts fit into the system. It requires one to zoom in on a specific part of the plant, and thoroughly understand its functions and principles behind its processes to comprehend how it fits into the overall system. Once again, as participant 07 (ECT, CE) shares, one valve may not be a “*huge thing, and can be very small*” but he must still be knowledgeable of the way that it works and what is the exact role it plays in the overall plan. It is only then that one is able to assess if the smallest of things can have the largest of consequences on the system. This is not always, however, immediately accessible knowledge. Participant 07 (ECT, CE) continues describing how he learns the details of this specific technical equipment, first lamenting that during work he cannot really deconstruct it and reflect on it:

*I wish I could, I wish I could. but uh. we all don't have the luxury of um doing that. I really wish I could do, but we don't have the luxury of doing that. So, what, the best I can do is I'll just go online, go to the internet, search as much as I can about JT valves um, videos, theories, to see the cross-section of how it works, and then I will get a rough understanding of how this valve works. it might not be the exact model I'm using at my site, but you get the principle of it. and once you get the principle of things, you tend to, a lot of other things that follow the same principle tend to fit. (Participant 07, ECT, CE)*

What is also noteworthy is that the process of understanding a plant actually takes place outside the plant, because he does not have the luxury of time when he is in the plant itself. To make up for that lack of opportunities to be in the plant, he actively researches on the internet to watch videos and read different theories to better understand the valve and the basic principle of how it works. This is in line with what we have discussed in section 3.1 where we argue that experience and time do not necessarily lead to the attainment of mastery. Instead, it is one's concentrated efforts and how they spend and make use of their time which determines the quality of the experience they have. When understood in the context of developing a deep embodied understanding of the plant, this implies that if one does not have many opportunities to be in the plant, it is still possible to develop an embodied understanding of it. Having some practical experience of the physical plant is a prerequisite of course and developing a feel for the ground is significantly more difficult when that ground is far away. However, self-initiative and taking time to learn and study the different equipment and processes in their own time, even if they are not completely similar to their companies, can support professionals in this regard.

### Knowing who to access in the field/plant and actively communicating with them

Due to the sheer size of the plant, it is often impossible for one to know everything about it, hence individual technicians or engineers are expected to have a rough idea of the overall processes of the plant with a specific engineer or technician being in charge of a particular section. Therefore, developing a deeper embodied understanding of the plant comes with actively communicating and knowing who is in charge of which section and who should one access to learn more about it.

A prerequisite for such active communications is knowing who is where in the system. The following findings illustrate this interplay between knowing who to access and the act of accessing and communication with them:

*So, if let's say we have, we notice there is some leakage, where is the leakage most likely to be? So we come up with possibilities based on experience, which can be gained or can be learnt from other more senior people and also based on the stuff that we have learned on paper or both in university or in the company itself (...) So that leads to another important skill which is to, I think, to effectively communicate with colleagues because each of the engineers will likely be responsible for just one part of the plant and there will be maybe 10, 20 engineers responsible for this entire plant that makes 1 single product. So, they need to be able to communicate, to exchange their ideas or suggestions or let's say when they are troubleshooting together, because something that goes wrong in this part of the plant may be due to reason that is elsewhere in the plant, like further upstream or further downstream. It is important to work with people and to communicate (...) Normally the entire team knows roughly how the entire plant operates and there will be experts in the specific section they are responsible for. But most of the time it's not possible to know every single detail in the entire plant. That's why they need to be able to look for the right person if they want to know something more about the other parts of the plant. (Participant 04, Student, CE)*

What is noteworthy about this extract is that he does not define experience in terms of how long one has been in the company but instead explains that experience is something that can be gained through learning from others by communicating effectively with them. This is not just applicable for younger professionals who may not be as familiar with the plant as compared to their older colleagues. Instead, every individual working in the plant should ideally be actively communicating with each other because as participant 04 (Student, CE) says “something that goes wrong in this part of the plant may be due to reason that is elsewhere in the plant, like further upstream or further downstream. It is important to work with people and to communicate”. Even as professionals in the CE and PE industries strive towards developing a deep embodied understanding of the plant, it is often highly unlikely to be familiar with every single aspect of it. Therefore rather than focusing on gaining knowledge about the plant through individual means, it is more practical to know who is in charge of which aspect and then actively learn and communicate with others.

In fact, the importance of knowing who to access, and collaborating and communicating with them to maximise one's understanding of the plant is also alluded to in participant 30's (ECT, PE) example below, explaining a training structure adopted by his company:

*I'm doing a product. So, I will be going through from the start of the product and from the first process right to the last process. We are currently manufacturing pacemaker lids. So, we're building the lids from start to finish (...) **So we have, just imagine, we have 10 technicians. So, from number 1 to number 10. Number 1 will actually be just focused on the first process. Then whatever that number 1 does, he doesn't know what the next process of what number 3 does. So, when I go in, I will complete the whole product cycle from 1 to 10 (...)** I've a lot of friends from different engineering industries, and what I gather from most of **my friends is they don't really spend much time with the ground technicians to really understand the pain or***

***understand the products and stuff. Because as engineers, we are mostly in the office, and then we try to assume what was the problem or what can be improved. But we're not really addressing what needs to be done. (Participant 30, ECT, PE)***

Just like how participant 04 (Student, CE) shared that there are multiple engineers or technicians working in the plant, participant 30 (ECT, PE) mentions that there may be 10 technicians working in a specific product cycle and each of them is in charge of and familiar only with one particular stage in the product cycle. Thus, for participant 30 (ECT, PE) to develop an embodied understanding of the plant, he would have to consult each of them individually to learn about the specific stage of the product cycle that they are in charge of. Participant 30 (ECT, PE) also shares how each technician's tasks and role is clearly demarcated which makes the process of learning about a plant more efficient because one immediately knows who to access when wanting to learn more about a specific aspect of the plant.

Moreover, participant 30 (ECT, PE) also mentions that as engineers who work in the office most of the time, their only way of getting to know the ground is by spending time with the ground technicians to understand the challenges of the different processes. Hence, participant 30's (ECT, PE) example reinforces the importance of knowing and communicating with different professionals working in the plant in order to develop a deep embodied understanding of it.

#### **Opportunity: integrating practical sessions, pilot plants, and workplace learning better to build embodied understanding**

So far, this section has covered the different factors that shape one's embodied understanding of the plant. They include their ability to visualise the ground, their competence in troubleshooting, their understanding of how individual parts of the plant fit into the larger system as well as their knowledge of who to access when wanting to learn more about the plan. Additionally, we have also alluded to how many of these skills such as their competence in P&ID, knowledge of the individual parts of the plant and communicating effectively with people who work on the ground, can be honed and refined even when one does not have access to the plant itself.

It would seem from the above that developing a deep embodied understanding of the ground is predominantly acquired at the company or workplace, meaning that one only gets to develop an embodied understanding of their ground when they enter the industry. Educational institutions, however, can attempt to come close or simulate workplaces in their curriculum but can only do so much. At the pilot plant we observed - a miniature plant and, thus, in many respects a representation of an actual plant - a technical executive of the pilot plant mentioned that the integrated pilot plant cannot compare with the actual plant that students will eventually work in when they enter the industry. The excerpt from the fieldnotes below illustrates this in more detail:

*The plant that they have in school is only a small glimpse of what is actually out there, but for the students, this is the biggest thing that they have worked on. He [the technical executive] does not feel optimistic that such training would help students to better their skills when they go to the actual plant because in his words 'you don't know how big the plant is until you see how big the plant is'. I also am aware that students may be busy with other things in their mind from the other classes and tests that they have. To put them in a class where they are only given one attempt to try this out and to expect them to be good at what they do with literally 2-4 hours of practical experience is not going to cut it. (Fieldnotes, Pilot Plant, 19 Nov 2019)*

Our research suggests that thinking this way might in fact be limiting, and potentially miss out on a powerful opportunity. Our findings also show that for our interviewees and participants, knowledge of the important traits that one must acquire and the actions that one must take in order to develop a deep embodied understanding of the plant are usually gained during their practical sessions at school. Schools can approximate what is needed.

*I think during my practical session really helped a lot because during the practical sessions, now that I think back it's really very simple job that at that moment, the pressure given by my lecturers to like certain questions that she poses, like why is this valve closed. What do you do when so and so happens. Like that. Her presence is there to pressure us which really panic us 'la. Just training on quick thinking and quick analysis. I guess that helps. (Participant 02, Student, CE)*

As participant 02 (Student, CE) mentions, it is through practical sessions where certain values are inculcated, and students realise for themselves the importance of having certain traits such as being diligent or being able to think analytically, were picked up during practical sessions at school.

Meanwhile, participant 31 (ECT, PE) also shares that it was in his practical sessions where he got to appreciate the practical, physical, embodied aspect of manufacturing and designing something:

*In our practical we had to physically um, machine out certain parts. So being able to, forcing us to physically machine out was actually, makes us have an appreciation that sometimes right, it's a lot more complicated than we think, and some things in design we have to take into account. if I hadn't gone for these practical sessions right, I might not be able to understand the certain things I have to take into account, for e.g., um dimensioning. If I were to put a dimension a certain, only only like 2 decimal places instead of 3, then I will be a lot more inaccurate. so. and then that might affect the whole the preciseness of a certain equipment. So yeah. (Participant 31, ECT, PE)*

Unlike learning about manufacturing through theory, having a chance to physically manufacture something exposes one to all the factors that one has to take into account, and that designing something is actually a lot more complicated than one thinks.

The differing opinions between the technical executive and participant 02 (Student, CE) and participant 31 (ECT, PE) suggests there is a missed opportunity to develop a deep embodied understanding that starts with practical sessions in school, is sharpened in the workplace and strengthened through facilities like the pilot plant. Theory and practice can be better integrated, so that what is invisible is made visible continuously, and the professionals in both the CE and PE industries can deepen their grasp of the system and its many parts.

Overall, this section has covered what it means to have a deep embodied understanding of the ground. In fact, having a deep embodied understanding of the ground shares many similarities with chapter 3. In addition, this section has also reinforced the invisible nature of mastery, showing that one is only able to appreciate and recognise for themselves the things to look out for and the attributes to acquire when they are on the ground and given the opportunity to apply theory to practice. Thus, this shows the indisputable value of including practical sessions in the curriculum or providing students opportunities to access an integrated pilot plant. Having discussed the various ways that shape one's level of understanding a specific workplace or plant, the next section will discuss what it means for one's skills to be transferable across different products, plants and processes and why this is an increasingly important aspect of mastery today.

## 4.2C Transferability across different products/processes/plants

*One thing that was interesting today is how the Pilot Plant is a scaled down version of an actual plant. As a result, there were instances the new lecturer would actually need to take a minute or two to stop and orientate himself to the standalone units before he could explain what they were. I found that really interesting because I expected as a scaled down version, that things would be easier to understand! But perhaps, in this case, when one is used to working in a specific plant as a complex system, that plant becomes the new normal and anything else the 'weird' one (Fieldnotes, Pilot Plant, 7 January 2020)*

*When I return back to the class, the group that was just working on a very practical troubleshooting exercise is now working on some very complicated formulas on the board. I'm surprised with how theoretical it suddenly is. This shows the broad diversity of tasks that chemical engineers need to master: from more hardcore theory and solving formulas, to the much more practical and delicate process of lab experiments, to controlling production processes via the control room and to actually working with the massive machinery of the plant (Fieldnotes, Pilot Plant, 22 October 2019)*

The previous sections discussed the importance of feeling the ground and what it means to develop a deep embodied understanding of the ground. Another aspect of mastery when it comes to understanding work environments is the extent to which one is able to transfer their skills and expertise across different products, processes and plants.

If the previous section is about going deep, this section is about going wide. The ability to go wide and apply one's expertise across different plants, processes, plants cannot be taken as a given that comes inevitably with years of experience. Experience is, of course, important. The conventional conception of expertise and mastery is one that is associated with experience, where those who possess many years of experience are often regarded as possessing skills and insight that are extremely valuable to the company. This point is also mentioned often by our interviewees and participants:

*So, for example, somebody that has been working in a particular area for a good 20-30 years. So when we ask them questions. They will be able to articulate even to the theoretical fundamentals. So for example if I were to go to the UK, the experts are those that have been doing the same thing for 30 years, and when I ask him a particular question, he will basically be able to tell you why the particular engine is designed that way. So they know the fundamentals, I think that's the difference between a mediocre engineer and a specialist. Depth of knowledge. (Participant 41, MCT, PE)*

There is however a risk with experience if it is too specialized and specific to keep up with the changes taking place in the CE and PE industries today where professionals are expected to experience multiple types of workplaces and environments. In light of the above, being overly specialized is only a certain type of workplace or environment or to only have skills and expertise specific to a certain sector may be disadvantageous for professionals in the CE and PE industries.

### How experience can make one's skills less transferable

*After 4 years in the field, I started to compare my friends' career and mine. On the surface, yes, I probably earn more than them. **But the work they are doing, so by now ah, right now, they will probably be, I would say 4 to 5 years working experience, can probably be manager at the end of 3 to 5 years.** So, when you become a manager, you get to learn things that are out of what you are specialised in, for example if you were to be an engineer who has 3 to 4 years technical work experience, you will probably be promoted to be involved in a management role or*

*asked to do something apart from just technical work, right. But if you are staying in the field, yes you get paid a lot. but you don't, you don't learn so much of the other skill set. Such as soft skills or other core functions, like you don't learn about T&L, you don't learn about accounting, you don't learn about cost function. All these kinds of things, because on the field, most of the time, you will be the only engineer there, and there are very few opportunities to learn things outside of your work. (Participant 23, Retired, CE)*

In the example above, participant 23 (Retired, CE) shares his apprehension and worries about the limitations of his skillset and his lack of familiarity with other sectors of the industry compared to his peers. In addition, some of our interviewees also brought up how the COVID-19 pandemic and the instability of the Oil and Gas industry have caused them to start thinking of other alternative careers that they can take on in the event that they are forced to leave their job. As participant 12 (MCT, CE) shares:

*I think you, you might have, I mean, noticed that the current oil price, yeah, it's quite, it's quite worrying for everyone, in fact. I have survived, how to say, I've survived 3 crises. Yeah. But you don't know, nobody knows, you know, what's, going to happen, in time to come, and, yes, we still need, this, oil to, to live, the world still depend on this, economically, but we don't know, in time to come, that this could be a, a good prospect, in terms of career wise. Because it's, it may not be as stable as before. Those days, 30, 20 years ago, you can say that this is the, you know, the big thing, for a career, but now, nothing is promised. (Participant 12, MCT, CE)*

However, what further worries him is the niche of his current skillsets and how they may not be readily transferable across different sectors and work environments. This has also resulted in him lacking a clear idea of how to go about retaining and upskilling himself:

*This oil and gas job is a very niche career, you know, very specialized. Not everyone can do it, not everyone knows it, you know? So, it's something that, when you're talking about re-training, it's, we're quite, how to say, you need to, tell yourself that, hey, you cannot, depend on this industry, for long. I can't just say that, I want to start preparing now, because, I don't know what, I mean, when you talk about retraining, it's a very grey area for me. Like, what can I do, where can I start? (Participant 12, MCT, CE)*

Therefore, both examples show that even whilst specialisation in a particular field has its own benefits, professionals who are overly specialised and are unfamiliar with other sectors in the industry face the danger of being unable to transfer their skills and expertise across different workplace environments.

The importance of being able to transfer one's skills across different products, processes and plants is because workplaces in the CE and PE industries are highly unique and different from each other. This is particularly prevalent in the CE industry where our interviewee, Participant 08 (MCT, CE) shares with us that *"whenever you go to a new company, there are trade secrets. There are formulae, there are processes. All these you have to relearn"*. Meanwhile, for the PE industry, participant 42 (MCT, PE), commented:

*What we are trying to do is really to set a new way of designing products. Here the approach is we are trying to push the boundaries more and more, we're trying to do multiple product launches at a start-up level, and you know try to produce those robots, manufacturing everything, at the same time do all the development in house, there is no outsourcing. (Participant 42, MCT, PE)*

Their examples highlight how the workplace environments at individual companies differ from each other, but even within companies itself the products and processes that they work with are constantly changing. In addition, with digital transformation currently taking place and companies being at different stages of technology adoption, this has further differentiated work

contexts and settings. This has implications for technical professionals, given that they are now expected to traverse between different processes, products and plants more frequently than ever before.

This implies that beyond having a deep embodied understanding of a particular plant, product or work process, it is also important for professionals in the CE and PE industries to be able to transfer their embodied understanding and skills across different products, plants and processes given the diversity of workplaces and contexts. Thus, the next part of this section will proceed to explore how professionals in the CE and PE industries can equip themselves so that they will be able to transfer their knowledge and expertise across different products, processes and spaces.

### Being flexible with fundamentals and core competencies

*Like my boss always says, don't over train them for the industry. When they go into the industry, they might have to look at different machines. Same type of process, but different machine brand. Then how? Then you will have a lot of inventory to come in (...) You settle the fundamentals, like if you operate the lathe, you know what the tools are, how to set up the tools, and what the machine can do. You can turn the track, you can turn the difficult component, that's all. When you go there, you may handle a bigger machine. Then you look at it, and you start all over again. Look at 3D printing today for example. We have 101 brands of 3D printers. Are you going to train them in all the brands? Every brand has its features, and the operating system might be different. But what's important is that you must know that you need a model, an stl file model. You need this kind of material. And how to set up, how to set the machine. You must set up the orientation, and then you must know their filaments, and then you go. And with that experience, you learn from there. That's why for Industry 4.0, it's not new, it's something how to adapt, put, integrate different technology and assemble it. There's nothing new. It's there already. Adapting is more important. (Participant 84, ET, Other Stakeholder)*

Participant 84 (ET, Other Stakeholder) shares how educators or superiors must be careful to not overtrain students or employees. Given the diversity of processes and equipment and work settings, it is possible for professionals to be working with equipment and processes different from those that they had been trained in. Therefore, rather than placing an emphasis on learning how to use new or specific machines, participant 84 (ET, Other Stakeholder) shares that it is more important to train students in the fundamentals given that having strong fundamentals is ultimately what enables professionals to adapt them flexibly and transfer their skills and expertise across different products, plants and processes.

Our findings from the CE industry are similar to that of the PE industry. During our fieldwork observations at *Pilot Plant*, we observed an instructor teaching his students about symbols in the P&ID diagram:

*To complicate things more, not all symbols in the P&ID diagram are standardized, some companies use other symbols for specific valves or gauges, or sometimes they use very antique or exotic ones that are used nowhere but in that specific plant. The P&ID is the core competency of a chemical engineer". He repeats what I've heard a few weeks ago, saying that even though plants already have P&ID's (unless it's an entirely new plant perhaps), professionals still draw the diagrams themselves. (Fieldnotes, Pilot Plant, 26 Nov 2019)*

The instructor mentions that companies may use different versions of the P&ID and that symbols in the P&ID are not standardised across the board. While most companies may have their own version of the P&ID and provide them to their employees, the instructor believes that

every professional should be skilled in P&ID and be able to draw their own P&ID themselves. This will be especially useful when one is required to work in a plant they are not familiar with. In which he further shares about his experiences working at a plant overseas.

*While talking something interesting comes up, as **he [instructor] shares stories about the line-tracing (this seems such a common and recurring theme – it's apparently really important for technicians)**. He tells how he would use the time of the long commute from his house to the new plant in Tokyo to read his P&IDs, which was a huge file as it was also a huge plant they were opening. He highlights how this line-tracing is important to not just do as a student but to keep doing it as a working professional. The physical plant itself can be so overwhelming because of its complexity. "You need to understand the drawings, and then, from there, you can understand the plant. If you can read the drawings and look at the plant, you can see how healthy it is and how the process is going". (Fieldnotes, Pilot Plant, 10 Dec 2019)*

As one can see from the instructor's personal experiences, he would rely on line-tracing and reading his P&IDs to better understand plants that he was not familiar with when overseas. Therefore, for one to transfer between different products, plants and processes smoothly, one must first possess strong domain fundamentals. More specifically, these fundamentals need to be developed in such a way that they do not encourage rigidity or overspecialisation but, on the contrary, need to facilitate their application in flexible ways across context.

While the brands of the equipment and the types of the processes may differ from each other, their fundamental principles remain similar:

*So, there's – for every technology, there's a foundation, there's a concept behind it. For example, 3D printing, the concept behind it is – the concept behind it is mechanical engineering. There's a lot of thermodynamics involved there's a lot of design or precision engineering involved. So, being equipped with precision engineering skills prior to moving into 3D printing would definitely help. Or any sort of manufacturing knowledge, having knowledge in manufacturing, very old school industries where manufacturing, like die cast, moulding, sandblasting, all sorts of current or previous traditional methods of manufacturing will definitely help going into 3D printing. (Participant 38, MCT, PE)*

The example highlights the invisible layered nature of mastery in the digital age. While it is easy to be overwhelmed by the diversity of brands and new technologies in the company, participant 38's (MCT, PE) sharing underscores how one should focus on how to be agile in adapting the foundations and concepts behind the technology that are not as readily visible. More often than not, the concept and foundations of new technology are built upon traditional knowledge and engineering foundations. Therefore it is vital for one to possess strong foundations so that they will be able to recognise the foundations and concepts behind a certain technology and flexibly apply their skills and expertise when learning them.

### **Change with the changes and with others**

Apart from possessing strong domain fundamentals, our findings show that being dynamic and adaptable is essential in helping professionals transfer their knowledge and skills across different contexts and settings:

*So, the teams have to be super dynamic for a start-up. I'm putting it in a start-up context because it's more applicable right. So, let's say how we were running the team last year, if we run the same way this year, there's no way we'll be making progress. **Okay, so the whole way we do the team, the whole mindset, everything, has to evolve with respect to the company's growth.** So, this is one thing where we spend a lot of time with the people who have high potential to grow faster is that **you have to keep evolving the way you think. It's not just about what you are doing, because let's say the company is trying to move towards a new direction. So now let's say we***

**are building robots. The company is trying to start building drones. If the engineers don't change the mindset and start thinking about drones, this team will become dysfunctional.** Yeah, so the biggest challenge is always how to maintain that sort of dynamic environment, where as a company is growing, the same growth, we can get in the team members as well. (Participant 42, MCT, PE)

While a start-up environment is very unique and contextualised, it provides a good example for how one can cope when they are required to work with different and new products and processes. The example reinforces the earlier point made that it is hard to predict what kind of processes or products one will work with in the future. It is almost impossible to be trained in all of the disciplines, processes, products, equipment available. Therefore, beyond focusing on technical engineering foundations, an equal emphasis must also be placed on helping professionals in the CE and PE industries to be dynamic and comfortable with the fast pace of change.

More than just adopting the right mindset and attitude, one should be proactive in picking up new skills and disciplines that are relevant to their work. Participant 47 (ET, PE) who has gone through multiple job changes and transitions throughout his career shares his experience with how he had managed to move between different projects and companies:

*I also go for training, night class training, attend courses, over the years (...) I had to tell myself that when the industry has developed, we have to follow suit, otherwise we will lag behind because a lot of manual machines are going to be replaced by computerised machines. (Participant 47, ET, PE)*

Beyond the need for individuals to adopt an adaptable and proactive mindset when moving between different products, plants and processes, we have also seen how organisations are attempting to instil a culture open and receptive to change at an organisational level as well. This is done so by setting up a dedicated team that is in charge of change management, which can be seen in participant 21's (ET, CE) example below:

*I mean there are things like change management you see, **when there's these types of projects coming up, the good companies will bring some type of change management to the project as well. Which is about communicating the change, how do you train people, how do you gather feedback and so on and how do you make sure that it's still, and this new tool, this new way of working sticks. So, I think change management is one part of it. The good companies do that alongside being in technology.** Yeah I think, a lot of the other elements are just sort of subcomponents of changed management. It's about communicating. I think there's also communication from management to people explaining to them that this is why this is taking place, this is what it means, and these are the implications. (Participant 21, ET, CE)*

Participant 21's (ET, CE) example shows that companies play a huge role in shaping their employees' attitudes towards change and the need to pick up new skills rather than merely introducing changes that will occur and expecting employees to accept and adapt to them. Companies need to look at how they can communicate these changes to their employees in an empowering and reassuring manner, providing their staff with the training opportunities and platforms so that they can be upskilled and take time to gather feedback from staff about their thoughts towards the change and whether the change implemented was a valuable and productive one.

In addition, participant 09 (MCT, CE) shares how he feels that the reason why his colleagues in the company, even the more senior ones, are not as resistant to change and open to pick up new skills and learn about new technologies. For him, this is because his company has

been very consistent and intentional in inculcating a specific type of culture where they are often raising employees' awareness about the different technologies out there and making technology a part of their daily lives.

Overall, this section has discussed the importance of one's ability to transfer their skills and expertise across different products, plants and processes and how it is an integral aspect of mastery in the digital age. In addition, this section has also reinforced the invisible, layered and multi-dimensional aspects of mastery in the CE and PE industries. Rather than becoming overwhelmed by the prominent - the diverse range of products, plans and processes out there, one should take time to discern the foundations and concepts behind each of these products and processes and seek to apply their present skills and knowledge to them. At the same time, it is important to recognise the significant role that companies play in helping their employees transfer their expertise between different types of products, plants and processes. As products, plants and processes change, what constitutes mastery will also change alongside it as well. Companies and individuals must work alongside each other to discern the essential skills and qualities that they have to develop to ensure that they will be able to continually thrive in the future.

#### 4.3 **Conclusion**

As a whole, this chapter has looked into the importance of feeling the ground despite the increasing prevalence of technologies that allow one to "control" the plant (CE) or to perform tasks on our behalf (PE). This is due to the wealth of information embedded within the plant, the need to complement symbolic representations of the plant with a physical, sensory knowledge and the social, acculturation aspect of working in the plant as well as the need to assemble a product using one's physical embodied senses. Subsequently, we went on to discuss what it means to have a deep embodied understanding of the ground which includes the ability to visualise the environment one is working in concretely, be able to troubleshoot and inspect incisively and knowing who to access in the ground. The chapter ended with a discussion on how one can develop the skills that enable them to transfer their expertise and skills across different products, plants and processes instead of being familiar and knowledgeable only about one specific plant.

Experts must also be increasingly able to transfer their skills into the future. This is an increasingly important aspect of mastery as we witness changes and disruptions at different scales and levels take place in the CE and PE industry. This provides a nice segue into our next chapter where our report will examine how secular trends in technological, business and locational disruption could change future mastery. We analyse this through the lens of the pandemic, which accelerated many of these trends, and hence gives us emerging and early signals of how they have impacted and can impact what constitutes mastery.

## 5. Exploit technology, business and locational disruption (through the lens of a pandemic)

Our study is based on the premise that technology has changed the conventional conception of mastery. As technology evolves, the conception of mastery will evolve alongside it as well and the pandemic has provided us a glimpse of how mastery will evolve in the future, albeit in an accelerated manner. Our findings in chapter 5 provide a first-hand account of what it means for mastery to evolve alongside technology, where our interviewees and fieldwork participants shared with us their experiences with technological, business and locational disruptions and the resultant skills that they had to pick up due to these changes. Their experiences highlight their initial responses towards these changes and the challenges they faced having to pick up the new skills, given that the pandemic is still ongoing. In fact, our findings reveal that most of the companies that our interviewees and participants belong to were not well-prepared in terms of business contingency plans to guide and train their staff in handling technological, business and locational disruptions. This reinforces what we previously discussed in section 4.2C about the significant role that companies play in empowering their employees to develop mastery in the digital age. This has also highlighted the need for the CE and PE industries to start thinking about mastery that is required for the future, on top of helping professionals develop mastery that is relevant for the present. Therefore, this chapter will be more speculative in nature, as we examine how the CE and PE industries have fared in terms of training professionals in new aspects of mastery that were precipitated by the pandemic.

The COVID-19 pandemic has not only accelerated but also necessitated some technological, business, and locational changes to work. Given that the pandemic took place amidst this study, some of our data naturally made direct reference to the consequence of the pandemic and how work in the CE and PE industries have changed since. This chapter is therefore warranted to explore what those data say about the implications these changes have on mastery.

It should be noted that it does not mean that how mastery is distributed here is contingent on the presence of a pandemic. The changes happening to work such as the increasing prevalence of remote work were already slowly taking place even before the pandemic; the pandemic has simply accelerated the speed of change to an unprecedented degree. We posit that with or without the pandemic, ideas related to exploiting technological, business and locational changes and how they constitute, challenge, or even facilitate particular aspects of mastery will continue to be relevant given that this is the current trend the CE and PE industries are heading towards.

This chapter is particularly exploratory and arguably raises more questions than answers. The relevant data from the interviews and observations conducted mainly highlighted problems that people encountered from the pandemic, rather than solutions to these problems. This could be partially because the pandemic has not come to a closure and these industries are still in the process of figuring out what the solutions should be, also given that a pandemic could not have been accounted for when we planned the study. While the findings of this study are not enough to shed light on how people can attain mastery related to thriving under recent work changes, they are enough to show us what this particular aspect of mastery constitutes. Hence, the open-ended nature of our findings here provides valuable areas which future research could look into.

The modern workplace is always changing because of technology and business strategies. This has a bearing on the spatial configuration, location of the workplace, as well as platforms and tools that will be the most productive for carrying out work. This has an overall impact on the ways of working. This phenomenon was especially pronounced in the past year where we witnessed remote work become the new normal. Hence, the COVID-19 pandemic has demonstrated that leveraging business, locational and work changes is another important aspect of people-technology mastery. The right use of technology allows one to work remotely, collaborate effectively with people remotely and accomplish physical tasks without being physically present.

Below is an example where a focus group participant shares how remote work has required professionals to pick up new skills that enable them to collaborate effectively remotely:

*The last thing on remote collaboration, means now that you don't have your teammates in the field itself. **How can you actually collaborate with somebody who can actually remotely tell you information, or supervise in certain areas of the role that they are competent in?** These are all the key questions that the business continuity must address pre- pandemic and post-pandemic. One of the things that I wanted to say is that because the situation is very uncertain, there is a lot of uncertainty [downsizing].... Therefore, the individual has to actually have a certain type of self-mastery, meaning that he must be able to add value to much more processes than before. Therefore, he needs to find ways to value-add himself, so that he can fulfil a bigger breadth in terms of work role. But of course, **he can't be over-extending himself beyond too many technical aspects, hence some point of collaboration is also essential.** There are also calls for tighter cyber security training, there is an urgency to move towards to that, as we look to remote collaboration, we also have to look at the subject of cyber security, most important is for the person to be at the field itself, he actually need to be more data-literacy.... (Participant 78, ET, Industry Expert)*

Participant 78's (ET, Industry Expert) example demonstrates how the new set of work arrangements under the pandemic has expanded the current conception of mastery in the digital age. This entails the ability to collaborate with people effectively albeit doing so remotely, the need for professionals to be skilled and knowledgeable across different skill sets and also for them to acquire cyber security knowledge. Moreover, his example provides a brief glimpse of how technological, business and locational changes have reshaped what constitutes mastery in the digital age.

This section will proceed to discuss three different areas that we think constitute what it means to exploit business, technological and locational changes to one's advantage. They include:

- 1) Collaborate, coordinate, innovate, and train remotely;
- 2) Traverse cyber-physical spaces; and
- 3) Respond to increased global competition.

These issues make the people-people interactions described in chapter 3 even more important, because people-people aspects of mastery become increasingly difficult to acquire and develop when individuals do not share the same physical space. Finally, the rise of remote work has shown companies the possibilities and potential of remote work arrangements. This provides a challenge for Singapore, as remote employees need not be based locally but can come from all over the world. Consequently, this has increased the level of competition, given that one's competition is no longer just limited to those within the same country but now includes people from all over the world. Therefore, the last aspect of being able to exploit technological, business and locational changes requires being able to stand out amongst global competition.

## 5.1 Collaborate, coordinate, innovate, and train remotely

One major area which the pandemic has affected workplaces and industries all around the world is that of communication, collaboration and coordination. With the introduction of social distancing measures and remote working, a lot of collaboration and coordination is now conducted remotely instead of face to face.

### Potential of online learning and training to be as effective as in-person learning and training

The CE and PE industries are no exception, and our findings have shown how the pandemic has significantly hindered collaboration and coordination, particularly in the area of training and inspection. With training being cancelled or moved online, several of our interviewees have remarked to us how online training has not been as effective as training conducted face-to-face. This can be seen in the examples shared by participants 13 (MCT, CE), and 41 (MCT, PE) below:

*We were supposed to go for training for this new tool in the US, but it was cancelled. So, for now, we have to communicate by email, video, and from outside. Yeah. So, it's quite difficult...I really like to meet them in person. Like I want them to teach it to me live. So, I can ask everything directly, I would get an answer directly instead of having to wait for them. Sometimes we need to wait for them to reply because of time difference... Again you need to wait, you can't continue with your job because like – you have to wait for a response from them. That's really frustrating sometimes.*  
(Participant 13, MCT, CE)

*We have trainers flying from all over the world to Singapore, to conduct classroom-based training. But if you talk about performance, thermal systems, that kind of specific area, typically from my experience, I sit down beside a specialist for 3-6 months to learn from them, face to face. So, if you talk about remote training in these kinds of areas, it's probably the first time. So, for example, give you a fluid system. So, I want to understand how the oil system, air system works in the engine. So, I basically sit down in the fluids modelling team for 3-6 months. So, you have the relevant software installed in your laptop. Then they will give you assignments or investigations to work on. Then they will give you tutorials for you to read and follow. So, the benefit for me to sit down in their team physically is that I get to ask questions, I get to be part of their discussions. That itself, I think that is 80% of the training. To be involved in their day-to-day discussions. **That's where you learn the most. And I feel that it's really a waste because we can't travel to the UK and sit down with them anymore.*** (Participant 41, MCT, PE)

Participant 13 (MCT, CE) and participant 14's (MCT, PE) sharing reinforce what we previously discussed in section 3.2C about the importance of socialisation and dynamics in the learning process. As participant 14 (MCT, PE) shares, 80% of the training comes from being able to sit down beside an expert, observing their actual work processes and being able to ask them questions directly on the spot. However, online training often does not allow one to have their questions answered directly on the spot.

At the same time, participant 38 (MCT, PE), a Robotics trainer believes it is a critical aspect of learning:

*I would feel 1 of the things is – there's a lag in my support. For example, I'm a trainer and you have a question, you're in my training, you have a question for me. So do 10 other trainees. They have questions for me. Being able to face them, I can just generally, ok, let me answer 1 at a time and get everyone to probably address them accordingly. But being online, some trainees are more reserved than others. They send me private messages then I have to individually reply to them, for example. So, I think – that's not a very good example of support but it's just that because of digitalisation, because I'm a bit further away, there's a lag in response. If you ask me a question now face to face, I'm more forced to answer you on the spot. **But if you ask me online, you know, I***

**could probably delay it for a while, and that delay might impact learning.**  
(Participant 38, MCT, PE)

On the other hand, our findings also show that some of the other interviewees we interviewed have experienced or taken a slightly different approach to learning during the pandemic:

*Back to the part of like learning through github right, like I think because of the availability of like source code on github, like I, it allowed me to like pick up the soft coding independently. (Participant 34, ECT, PE)*

*Participant 30 (ECT, PE): some of the skills right now would be, actually I'm learning to learn would be data analytics. So, from my plant, we generate a lot of data that is coming in. then its – we categorise it as big data also. From my side I'll try to – how do I understand all this so that I can predict what's coming for me? To prevent a certain event from occurring I can actually save cost for a company.*

*Interviewer 1: And is this a new initiative for the company? To make use of big data that they have.*

*Participant 30 (ECT, PE): correct. so it's actually in the transition phase. Before COVID-19 hit we were supposed to go for some courses offsite. But when the COVID situation started we had to put the project on hold. And then I didn't want to waste any time so I tried to google some stuff and tried to learn on my own first.*

For participants 34 (ECT, PE) and 30 (ECT, PE), whose training plans were disrupted by the pandemic, this did not stop them from pursuing their own learning independently, where participant 34 (ECT, PE) made use of Github, an open source code management database to pick up different types of programming skills. While participant 30 (ECT, PE), “*did not want to waste any time*” during the pandemic, and began researching certain things and learning on his own as well.

On the other hand, participant 19's (ET, CE) company also tailored the contents of training taking into the account that it is being conducted online:

*Participant 19 (ET, CE): There is also training involved as well, training online. **Because in my kind of scope there are things that we need to be familiar with, procedures that we need to know and kind of behaviour that we need to understand. So, some theories that we need actually apply. So, we need to understand our company's philosophy.***

*Interviewer: So, these trainings are online conducted by the company or external providers?*

*Participant 19 (ET, CE): **By trainers from our company. At the moment, this is how online training takes place that the lecturers present themselves, they have their own PowerPoint slides there. And some videos of course.***

As participant 19's (ET, CE) example highlights, the contents of his online training had a stronger theoretical emphasis rather than hands-on nature, where he picked up theoretical content and information regarding his company's philosophy. Therefore, even though training was conducted online, the quality of training was not compromised to a great extent. This also shows that online learning and training do not have to be inferior to in-person training.

In fact, it is possible to make training more practical in an online medium than a face-to-face one. This is mentioned by participant 01 (Student, CE), who shares with us why face-to-face training may not always be the most beneficial or practical:

*Because like my diploma ... okay my batch is 240 people and there's a limit to how many people can visit a plant and there are a lot of administrative procedures to be cleared and ermm generally at most only about 60 people can go at once. So, if it can be brought to us first, then people that are really really actually interested can then sign up for the limited amount of slots to actually go down themselves and then find out more. Rather than everyone goes down and then half the people are not interested. So, it's a waste of time and resources that way. (Participant 01, Student, CE)*

As participant 01 (Student, CE) shares, conducting face-to-face training especially when it involves being in a physical plant itself may be quite logistically challenging and not the most conducive environment for a large group of people to learn. Hence, if one can learn about the plant and familiarise themselves with it through digital means before going down physically to learn at the actual plant itself, this could make the overall learning process more effective. Afterall, as we have also discussed in section 4.2B, developing a deep embodied understanding of the ground usually starts from having strong basic fundamentals and being able to understand symbolic representations of the plant, of which are skills that can be acquired outside of the plant. The challenge here is to provide online learning in such a way that it resonates with the practical reality of workplaces rather than seeing learning merely as transferring knowledge:

*So we have LinkedIn learning at our fingertips, we also have a cloud group, we have Udemy, we have literally a lot of things, and we also have our own company's "university" to be honest. Our "company's university" is actually an inhouse online platform where employees can just literally pick up a course and then, they will be certified. So even some of the things are mandatory, before they go onto this site, they have to pick up that course in [the company's] university for example. So that's some of the things that we have in house that contribute to the learning for a lot of these employees. (Participant 16, MCT, CE)*

What is noteworthy from our findings is that most of our interviewees' companies had to change and modify their training programs due to the pandemic, where the majority of them were either cancelled or moved online. However, for participant 16's (MCT, CE) company, online learning via their company's online university (a platform that allows employees to take courses) and the use of other platforms such as LinkedIn and Udemy were present even before the pandemic. Therefore, participant 16 (MCT, CE) and his colleagues were already used to online learning and training even before the pandemic. Moreover, participant 16 (MCT, CE) also mentions how opportunities for learning and training were not compromised even with the pandemic.

This shows that we need to expand our current perspective about how training can be conducted effectively in the future. The current impression of effective training in the CE and PE industries is one that is heavily dominated by face-to-face, in person training and learning. In fact online training or learning is often criticised for being less interactive and less able to capture the physical, senatorial embodied nature of crucial skills. Our findings suggest that it may not be an inherent failing of online interactions, but from organisations' and individuals' lack of mastery of this form of interactions. It can also be the case that learning on digital platforms does not sufficiently take into account the social and embodied dimensions of mastery. In such instances, learning is seen too simplistically as 'transferring' knowledge, something we also highlighted in section 3.3B as 'downloading'. Digital ways of learning may make it more challenging to incorporate these aspects of mastery, although, as our findings also suggest, this is not impossible.

For example, we described in section 4.1C how participant 52 (ET, PE) gets the engineers at his company to video themselves with Go-Pro cameras to capture the process of assembling a robot. This suggests how, when used effectively, technology can actually complement on-

the-ground learning experience. It does, however, imply that mastery should be considered in all the dimensions we have described in this report. If learning via digital means becomes an individualistic endeavour, we remain stuck in the conventional understanding of mastery as climbing the ladder.

Here is an example how an innovative use of online training and learning can help retain a collaborative nature:

*We have a database of case studies, past occurrences of certain things that have happened. If you read a lot of it, you read and read, maybe even memorise, it's not really necessary to memorise, really understand about the problem and the kind of solutions that other people have, have come up with to face a certain problem and that actually helps (...) We basically have sort of like a database where they have this thing called lessons learnt. It includes all the data they have of a certain equipment, what went wrong, what they realised upon experimentation, and also trying to solve the problem, right, how they solve the problem, and how things are now and anyone in the company can look at and learn from. It's voluntary, yeah. But to be honest, my company has done very very well. People are really sharing knowledge almost all the time. Because of the fact that if you were to contribute more into the system, you would become a subject matter expert and if you become a subject matter, it'll cause you and the subject to be noticed by management. If that is noticed by management, that means your rank in the company can probably, uh, can be raised uh. Different engineers have different levels in my company. So, you can raise your level within the company, that means more pay. So, being a subject matter expert has its perks. So, putting in more information about what happened can be good for you. (Participant 31, ECT, PE)*

Participant 31's (ECT, PE) example shows how one can make use of a simple technological tool which gives employees access to a wealth of information about the different equipment that can be used to promote learning in a collaborative manner. By updating the database about each employee's different experiences with a specific equipment, the employees are indirectly collaborating with each other to produce more comprehensive knowledge about a certain subject. In addition, the implicit reward system, where employees who contribute more are more inclined to be noticed and compensated by higher management also encourages employees to continually update the database, leading to a more extensive wealth of information and knowledge that the entire company can benefit from.

The examples above highlight three things in particular. Firstly, different types of learning and training content suit different types of platforms. While physical, sensorial embedded tasks and those that are specific to a certain workplace environment may favour face-to-face in person training, online learning is complementary when it comes to content that is more theoretical in nature. Secondly, the pandemic has shown us that online learning and training should not be viewed as a last resort or a trump card that is only made use of when face-to-face, in-person learning is unavailable. Instead, companies and their employees should take the effort to invest in their online learning and training platforms to complement face-to-face, in-person learning options and enhance the overall learning and training experience. Thirdly, remote learning and training do not have to be a solitary and uninspiring experience but can be leveraged in a way to retain the dynamic, collaborative and social aspect of learning and training or even enhanced.

### Remote communication and coordination – inherently limited?

Another difficulty noted was in remote communication, especially when it came to quality control and inspection. After all, communication over digital media such as video conferencing or phone calls is not the same as in-person communication, which may lead to inaccuracies and breakdown in communication. Phone calls, instant messaging and video conferencing do not allow information to be conveyed as precisely and effectively. Some of our interviewees were not used to the new remote working arrangement and found it challenging to communicate with their co-workers, given that the level of engagement is lower and some technical details are difficult to articulate in words. Therefore, deliberate attention and effort needs to be put in to ensure that remote communication is as effective as in-person communication. This is arguably also on the individual's part to learn and improve. As noted by participant 49 (ET, PE), who supervises a factory overseas:

*If face to face, it's very easy to solve the problem. I can tell you, oh I want this one. We can go back and forth like asking each other "Why are you asking me to go and do these specific tasks? And I can also explain Why I told them to do a certain task? We are always teaching each other. So, there is a very good touch point there. You can tell me "This one is wrong, I cannot do it, can you show me how to do it? And Then I will show you how to do it. So that is a practical way, really very good to solve the problem. **By using the computer, using the phone, it may create misunderstandings - because of language barriers.** So, the reason I can communicate with Batam is because I know how to speak in Malay. So, I will talk in the same language with them. they will understand. If I talk in English, then I go and check, hmmm. okay? so that's because of the language problem. Same as the computer also, when I send the message to them, sometimes they don't know how to read either, because their main language is Malay not English. We're using English to communicate with them. (Participant 49, ET, PE)*

While participant 49 (ET, PE) may have the privilege of being linguistically inclined and patient enough to clarify with his co-workers that they are able to understand him in full, this is not always the case. While phone calls, instant messaging and video conferencing may not be the best tools to convey technical details, our findings have shown that there is existing technology out there that can help to ease and mitigate the communication process. One example of such a technology is shared by participant 50 (ET, PE):

*Recently, we were being introduced to this innoglass product. It is an augmented reality smart glasses solution for industrial use and allows for hands-free remote assistance on top of being able to digitise maintenance records. It's a pair of glasses that allows you to zoom, you can either send a video or an image to the pair of glasses, the computer or the main unit, the main person that controls it. So, if you want to fix something, you can view the image being shown by the glass. So, it really helps especially when my colleague in Batam has a technical issue, then they can use the innoglass to show the problem to me. When using the innoglass, your two hands are free. So, your eyes can focus on the image with your two hands moving and working at the same time. It's even better than a handphone, because one of your hands will be holding the phone, and you only have one remaining hand to work. Or unless you can ask someone to hold the handphone for you, then you can do it. (Participant 50, ET, PE)*

Participant 50's (ET, PE) example highlights how remote communication and coordination can still be successfully carried out with the right use of tools and technologies. The *innoglass* (AR glasses) they use at his company afford two things specifically: communication and coordination with others in different geographical locations, and simultaneously a continuation of embodied experience. Whereas a telephone would be primarily one of verbal

communication, the glasses allow workers to contextualize such communication while continuing hands-on work. Professionals in the CE and PE industries should look at how they can improve their communication skills, by being more precise and specific with their language or using visual aids to supplement their explanations. Phone calls, instant messaging and video conferencing are admittedly not the most appropriate tools and mediums to conduct inspection and quality checks or communicate extremely technical information.

Hence this shows that remote communication and coordination are not inherently inferior to in-person, face-to-face communication and coordination. Our interviewees' challenges with remote communication and coordination during the pandemic point more towards their lack of knowledge in the appropriate tools and platforms to use for communication and coordination, as well as their inability to make the most out of the communication tools they have at their disposal rather than the inherent limitations of remote communication and coordination. Remote work is undeniably here to stay in the near future and mastering remote communication and coordination would mean knowing the correct tool and platform to use as well as improving one's communication skills.

### Opening possibilities for new types of collaboration

With remote communication and coordination becoming the norm, individuals are increasingly coming to realise that they are not only able to communicate and collaborate with people living in the same country, but any country for that matter. Moreover, events and workshops that have moved online are now more accessible than ever before. As we have discussed throughout the course of our report, being able to traverse different disciplines, plants, products and processes smoothly is becoming an increasingly valuable skill in the CE and PE industries today. One can also learn from a larger diversity of professionals belonging to different disciplines and sectors than ever before, because one is now able to communicate and collaborate with people from different countries. This is particularly helpful for CE and PE industries because it helps to break down instances of inter-disciplinary and inter-generational biases that are quite common in the industry.

Moreover, some of our interviewees already had the practice of communicating with different individuals from different offices worldwide even before the pandemic. This can be seen in participant 21 (ET, CE) and participant 30's (ECT, PE) examples below:

*None of them [are] in Singapore. So, I coordinate by time zone. So, I will start off in the morning with whoever I need to speak to in Asia or Australia, and then I wait for the middle east to wake up and the middle east calls and then I wait for Europe to wake up and Europe calls then it's the north America to wake up. So, you just go by time zone. It's a virtual team. (Participant 21, ET, CE)*

*It's more of initiating new stuff or initiating new projects where we have meetings with Germany even after our allocated work hours. Even at 6pm or 7pm we also have conference calls with them to see how we could actually improve or how we address some things we have to address. (Participant 30, ECT, PE)*

Collaborating remotely allows for networking and for different locations to learn from one another, especially since different locations focus on different aspects of operations. This benefit is not just limited to the pandemic times and should be reaped whenever possible. It should also be noted that it is not solely on the organisations' part to foster opportunities for international collaboration, instead individuals should be proactive to seek out the opportunities to do so effectively, as the following quote by participant 16 (MCT, CE) illustrates:

*So being a global company, I mean, even, **notwithstanding the COVID situation right now, being a global company, we have a lot of collaboration between different***

**companies.** so, for e.g., a lot of the use cases I'm working on are actually with the KL office, so with the KL office for e.g. I network with the people. and that's where I learn about the business on that side. I normally will wake up early in the morning in London to have a chat with them on these few cases for example. To learn more about business, I mean, for me, **I have to reach out to different people from different parts of the world. so, in India, for e.g., it's all about it, everything about the solutions are based in India. um. and then sg is about shipping and trading, so trading is in the sg's office, we have a huge trading floor in the sg's, um, I think marina bay office over there. and then um, in Houston, it's all about the engineering site. so that's how I get myself hands-on with the different parts of the business.**  
(Participant 16, MCT, CE)

Popular perception may argue that the pandemic has hindered our ability to communicate, coordinate and collaborate with others effectively. However, our findings have demonstrated that this is a one-sided examination. This section has shown that when remote communication, collaboration and coordination is done in an insightful and productive manner that supports rather than contradicts professionals' embodied mastery, it can be as effective as in-person, face to face communication and collaboration. This involves investing in online technologies and platforms as much as in-person platforms rather than viewing online platforms as a back-up plan. In addition, it also involves knowing what the appropriate tools and platforms are to use for which purposes and contexts and knowing how to make the most out of current technology available such as proactively collaborating with professionals overseas.

This section has also signalled to us the linkages between remote innovation, training, collaboration, coordination and what we have discussed in chapter 3 (multi-faceted mastery distributed across people-people interactions), and section 4.1 (experience, understand and use technology intimately, independently and intelligently). The concept of safe intersectional spaces where individuals of different disciplines, generations and professions can come together to mutually learn from each other can very well be held on an online platform, thus expanding ways to which we can collaborate effectively online. Moreover, we can also combine the elements found in safe intersectional spaces (section 3.2C) and multi-directional mentorship (section 3.3B) into an online platform. This helps to diversify the dominant type of instructional strategies on current online teaching and training platforms, where they tend to be in the form of online lectures and tests, thereby elevating the online learning and training experience. Finally, we also see how section 4.1C, in particular, the segment that touches on how one can use technology to improve communication, can also be implemented in how we can communicate and coordinate online better.

Indeed, it is evident that our section on remote innovation, training, collaboration and coordination will take up a major portion in this chapter, given that this was the primary, main concern our interviewees and participants focused on during our research. Moreover, given that remote innovation, training, collaboration and coordination form the cornerstone of remote work, we find that once we are able to establish a strong foundation in this area, it will have positive implications on the other two areas and allow us to be better able to traverse cyber-physical and respond to global competition.

## 5.2 Traverse cyber-physical spaces

Chapter 4.2 pointed out the importance of feeling the ground. It focused its discussion on the importance of going to the "physical" ground itself and honing the embodied, physical and sensorial skills that one can only gain from being in the ground itself. However, the pandemic also witnessed it becoming increasingly challenging for professionals to go down to the physical ground. They now must make use of digital technologies to ensure that they are still able to access and understand what is happening on the ground. While technologically

possible, this does not always bring the desired level of knowledge about the process. Therefore, it should be ensured that technology is used in such a way that the quality of work done remotely is similar to that of in-person work, and that the physical, sensorial, embodied experience of being in the plant itself is not compromised even if one is accessing the ground through digital means. Hence, this part of the chapter suggests that on top of the physical ground, there is also a “digital ground” that people need to gain mastery over.

Our findings highlight how cyber-physical platforms to carry out work tasks have been increasingly adopted in the CE and PE industries. They enable physical work to be done remotely, and training to be conducted without being in a physical plant.

Both industries are starting to experiment with remote control, and people interviewed expressed positive experiences with them. This is because remote control increases efficiency by cutting down travel time and also enables one to operate a physical plant remotely even if the plant may be in a different country:

*I would say actually it's helping me. Maybe we can remote control – remote control our customer PC, so actually helping me to travel to customer places.  
(Participant 37, MCT, PE)*

*They are now talking about remote control. So basically cut back on the operators on the field. Which is a very interesting way like you know, how you can activate troubleshooting offline. So you have people that are working from KL, who is able to monitor your plant here in Singapore. (Participant 09, ECT, CE)*

Industry experts also shared how business operations involving external stakeholders are moving to remote interactions and engagements where technologies such as live-video streaming are used, as seen in participant 80's (ET, Industry Expert) example below:

*One big one that we saw over the pandemic is moving to remote surveys and remote interactions with both regulators and vendors in that we can't get people to travel anywhere in the world, in a problem. **So the big one is moving and trying to get live video streaming for both survey, inspection and support for equipment, so I think one of our big shifts is to try to do it more and more cause again regulators don't want to lose time when they travel around the world....**Well it is physical against remote because it's about particularly where I talked about regulators, say we got class and society so it's an international clarification body of experts who provide regulatory response and sort of certification...There's also sets of rules for offshore installations and for us ships offshore installations so those needs to be inspected and audited and surveyors are obviously having difficulty travelling between countries and actually getting offshore to see it. And again we have sort of country inspectors as with MPI, Singapore Port Authority can't do port state of inspections because they cannot get onboard vessels due to quarantine, **so it's finding a way where we can actually use remote and sort of video conferencing to actually carry out inspections so they can be witnessed from an office at the end of a video link and that certainly is looking for the way, sort of a future way to do this so that this become much easier to actually do the inspections and also particularly where we look at needing to shut down or do work on equipment where it can actually be scheduled to make business sense rather than when an inspector is available to come and visit...** (Participant 80, ET, Industry Expert)*

Participant 80 (ET, Industry Expert) mentions that the introduction of live-video streaming during the pandemic has propelled his company to think about how they can use this technology to conduct surveys and inspections using live-video streaming for their plant more

often, especially with ongoing travel restrictions due to the pandemic. However, he also points out that the presence of strict rules and regulations must be adhered to when conducting inspections for offshore installations, and this complicates the process of using video conferencing to conduct inspections. Besides, the state of live-video streaming technology at his company is not developed enough to account for the different complications. Hence, this example highlights that even though cyber-physical technologies are increasingly prevalent in the CE and PE industries, they are not fully developed to the extent where the technological tools can afford the same efficiency and quality of work as being in the physical site itself.

Similarly, from our field observations at *Box Builder*, we found that the company invested in *innoglass* (AR glasses) prior to the pandemic and that these came into good use during the pandemic. However, as our example below will show, using technology to conduct remote checks auditing was much more inefficient compared to going down to the place physically to do so.

*The manufacturing manager talked about the difficulties encountered in managing operations in light of the COVID-19 pandemic due to unpreparedness. One particular problem that arose was the inability for auditors to do audit checks on the progress of the company's box building processes in person. Due to COVID-19 restrictions, audit tasks were subsequently done through WhatsApp, a social media platform. This change was particularly cumbersome, as the technicians needed to liaise with the auditors remotely, and had to constantly send images that captured different parts of the box-build with their own mobile devices. (Field Notes, Box Builder, 11 Dec 2020)*

Therefore, this suggests that much more needs to be done to ensure that physical work done through technological platforms are optimised. However, the COVID-19 pandemic has uncovered how many companies are still unprepared when it comes to having work processes be done in the same manner of efficiency and quality for cyber-physical platforms.

Virtual-reality (VR) training is another cyber-physical means that pilot plants have been adopting to make training possible without workers needing to be in the actual physical plants. It also allows a more hands-on practice of handling emergency situations. However, as noted from observations, the current quality of cyber physical training is not well simulated and immersive enough to achieve its intended purpose. For instance, we witnessed how the students at *Pilot Plant* would experience technical difficulties or experience headaches when they were using the VR goggles. Most importantly, the VR goggles do not capture the physical, embodied, sensorial nature of being in an actual plant. This means that while cyber physical platforms are being used, they are not that effectively utilised yet.

Overall, our data shows that the CE and PE industries are not fully prepared to exploit locational changes to facilitate remote work. This does not mean they are not fully equipped, rather, they are not utilizing their equipment enough to enable them to work remotely effectively. This means that not all the tasks can be done with the same expertise remotely. This issue was especially evident last year during the pandemic when remote working became compulsory.

Being able to traverse cyber-physical spaces successfully will become an increasingly important skill set in the future for professionals in the CE and PE industries as companies begin to embrace remote working arrangements that were precipitated by the pandemic. However, as our data has shown, companies need to take the lead in this area by exploring how they can more effectively make use of cyber-physical platforms to ensure that physical tasks and work processes can be conducted as efficiently and competently over technological platforms. This is more than just a matter of investing more in technology. It is about ensuring

that the technology available supports, and perhaps even improves, the expertise of technical professionals.

As we have discussed in sections 4.1A and 4.1B, indiscriminate and superficial understanding and use of technology can lead to detrimental effects when it comes to the physical, sensorial embodied skills and tasks that are a cornerstone of the CE and PE industries. Therefore, in designing cyber-physical platforms, one must firstly be able to experience, understand and use technology intimately, independently and intelligently. This will ensure that core skills and competencies are preserved and amplified rather than reduced and eliminated. Finally, it is also important to keep in mind that designing and developing cyber-physical platforms are not just about investing and adopting new or more developed types of technology but about knowing the appropriate types of technology to use and innovating with technology use.

### 5.3 Respond to global competition

A natural consequence following remote collaboration is increasing global competition. Given that remote working has become more common, companies are increasingly open to hiring foreign employees. Our findings show that even before the pandemic, there was already a notable sentiment amongst companies, not just in Singapore, displaying a greater preference to hire foreigners over locals due to concerns with labour cost. This can be seen in participant 23's (Retired, CE) example below:

*A lot of operations were actually remotely done. So, they were no longer flying engineers all the way from one end of the world to the other just to do this job, you know. It was all done via remote. and I remember that the remote centre is all located here now. This is because hiring workers who can work remotely is much cheaper.*  
(Participant 23, Retired, CE)

Moreover, as we have gathered during our focus groups with CE and PE industry experts, changing business conditions brought about by the pandemic has forced businesses to reduce headcount. Therefore, as the pandemic persisted, some employers caved in to downsizing pressures and reduced headcount to remain sustainable during the trying period. This entails that global competition has only been amplified by the pandemic and professionals in the CE and PE industries face more intensive competition than ever before.

Participant 12 (MCT, CE), who has experienced first-hand the lay-offs that his company has implemented shares the following with us:

*Recently. I've got friends in the States, where they just got laid off. I mean, it's very, sad, disheartening, you know, to hear your colleagues suddenly, it's very tough. It's not easy, and it's something, you know, you can't make fun of. You know? It can happen to us, anytime, any moment. So, it's a big thing, I mean, and then, you need to move on to the next, next step, what to do, you know, all this.* (Participant 12, MCT, CE)

Indeed, participant 12's (MCT, CE) mention of how lay-offs can “*happen to us, anytime, any moment*” is truly telling of the extent of uncertainty in the CE industry where even experienced professionals like him, with a wealth of experience, have anxieties about being laid off any moment.

In the same vein, participant 13 (MCT, CE) shares with us how her company has been laying off workers and the type of workers that are likely to be retained:

*I've been told that the lay-off is going to be ongoing, there's another stage, maybe 7 more people. So I just wait. What's going to happen? Yeah. Like for now they're just*

*selecting people to be laid off, such as those who are less experienced, for now. They're looking at keeping the multitask kind of technician that can handle a lot of jobs, like okay, if there are no tasks for this role, you can go to another department, you can do another job, something like that. (Participant 13, MCT, CE)*

Participant 13's (MCT, CE) example highlights that when companies are in the process of reducing head-count and attempting to keep labour costs low, the engineers and technicians they will look to retain are those that are skilled in multiple types of tasks and jobs. She also finds that because of her ability to transfer her skills across different products such as the *Icruise* and the *Geopilot*, she will still be able to contribute to her company.

Participant 13's (MCT, CE) point on the type of workers that are able to survive disruptions and lay-offs was also confirmed during our focus group with industry experts. As the pandemic persisted, some employers caved in to downsizing pressures and reduced headcount to remain sustainable. Two main issues were highlighted as a result of reduced headcount. Roles in the workplace need to adapt and be redefined as people work in smaller teams and take on additional responsibilities. Secondly, employers need to facilitate cross-training to deepen and broaden workers' skill sets.

How should technical professionals respond? As participant 78 (ET, Industry Expert) pointed out at the beginning of this chapter, *"the individual has to actually have a certain type of self-mastery, meaning that he must be able to add value to much more processes than before. Therefore he needs to find ways to value-add himself, so that he can fulfil a bigger breadth in terms of work role."*

Therefore, professionals who are able to perform a diverse range of tasks, as well as those who have both depth and breadth of skills have become more valued and sought after than ever before due to the pandemic. This aligns with what we have argued for in the rest of our report: a significant part of mastery in the digital age requires one to possess deep domain fundamentals (section 3.1A) and traverse across disciplines (section 3.2A) and generations smoothly (section 3.3A). At the same time, one needs to be able to experience, understand and use technology intimately, independently and intelligently (section 4.1A) so that they can work with technology in such a way that it elevates, rather than diminishes human expertise (section 4.1B) as well as be able to continually use technology in an innovative way (section 4.1C). Therefore, mastery is increasingly vital in order for one to thrive amidst increasing global competition.

#### 5.4 Conclusion

The pandemic has caused changes in technology adoption, business operations and the locationality of work. This allowed us to recognise the importance of being able to engage in remote innovation, training, collaboration and coordination effectively, traverse cyber-physical spaces competently, and respond to global competition. Our findings have shown us that the CE and PE industries are still at a preliminary stage where these three aspects are still very much lacking.

We have also pointed out some examples, particularly in the area of remote innovation, training, collaboration and coordination that provided possibilities on how the CE and PE industries can improve in these three areas. More importantly, our findings demonstrated how being able to thrive in these areas requires both people-people mastery and people-technology mastery, which once again highlights the multi-faceted nature of mastery in the digital age, where different aspects of mastery will become increasingly integrated and built upon each other.

Business, technological and locational changes that were expedited by the pandemic have opened up new ways and possibilities of working that are highly likely to remain even after the pandemic ends. Therefore, it is crucial that both professionals and organisations possess the specific skills, traits and aspects of mastery that changes in ways of working have necessitated.

We have discussed the possibilities of how our mastery concept relates to the skills and traits necessitated by businesses, technological and locational changes. We also acknowledge that these are given the unanticipated and unprecedented nature of the pandemic, our current mastery concept is not able to account for all of the aspects of mastery that the pandemic has revealed a need for. Afterall, the CE and PE industries are still in the process of attempting to make sense of current changing business conditions as well as future ones and the necessary actions to take. The pandemic has highlighted the importance of looking at what future expertise entails and how organisations and professionals can build up the mastery that is relevant for the present and required for the future.

## 6. Recommendations

766 years of combined practical ground experience. At least.

That is what the experience of all the participants across 250 hours of observations, 65 interviews and 9 focus groups add up to. Moreover, the observations were in two industries that have been under-studied ethnographically in the past. The insights we gained from our research were thus both novel and grounded, lending themselves readily to actionable recommendations.

We believe that our researching findings have the potential for broad applicability because of the range of operations we covered even as we should note that our research findings are from two specific manufacturing sectors and our recommendations thus, firstly, are aimed at these sectors. How well our insights allow for generalizability across other sectors is thus an extremely interesting line of continued inquiry. We explain why below.

We believe so because our research findings cover a broad range of operations (see Table 3 below). We studied a sector (CE) where the scale of operations is large and that is concerned with process innovation where the main external demand structuring the type and degree of this innovation is process safety. We also studied a company (*Box Builder*) operating on a medium scale and whose operations are focused on process innovation but under the demand of customer needs. Finally, we studied a company (*Cub Cleaner*) operating on a smaller and niche scale that is focused on product more than process innovation and where innovation in itself and the creation of a new market is of prime concern. The scale and nature of operations also had its impact on how digitalization affected work practices, specifically regarding the level of digital technology implementations vis-à-vis the necessity for physical work as part of the process.

	Scale of operations	Nature of operations	Nature of digitalization
CE	Large – Companies are a cog in a large production process	Process innovation under the demands of safety	Work practices are a blend of physical and digital work
PE (Box Builder)	Medium – Company works closely with customers	Process innovation under the demands of customer needs	Work practices are to a large extent physical, augmented with digital technology where applicable
PE (Cub Cleaner)	Small/Niche – Company develops niche innovations	Product innovation in creating a new market	Digitalization drives work practices

**Table 3: Characteristics of operations of companies**

Our findings cover these different operations which makes us confident that there is potential overlap with different sectors not studied in this project. Care should be taken, of course, to just take these recommendations as a given and they should always be considered in the context of the specificities of a company or sector. For example, we assume there may be significant differences between the sectors studied here – characterized by the incremental introduction of digital technology – and sectors that are characterized by much more rapid and intense disruption or, on the contrary, with sectors that are more reluctant to digitalization because of heavy reliance on a physical process. Future studies could try and seek out how well our model and related findings apply to these other sectors, thereby also contributing to articulating a reconceptualization of expertise – something we have only just begun to do here.

The recommendations based on the insights of our study are:

- 6.1 Design a Multi-faceted Mastery Model to guide the development of deep, distributed, and multi-faceted expertise in the digital age
- 6.2 Design targeted interventions (initiatives, incentives, and guidelines) for different dimensions of mastery
- 6.3 Track professionals' progress of mastery over time and at seminal stages of their careers
- 6.4 Establish keystone programs around keystone dimensions to cascade and accelerate the development of mastery in multiple dimensions
- 6.5 Gamify mastery to sustain motivation for the mastery journey and to encourage professionals to stay in the industry
- 6.6 Hack the digital age to accelerate mastery for the digital age
- 6.7 Upgrade pilot plants into 'petri-dishes' for future mastery

We elaborate on them below.

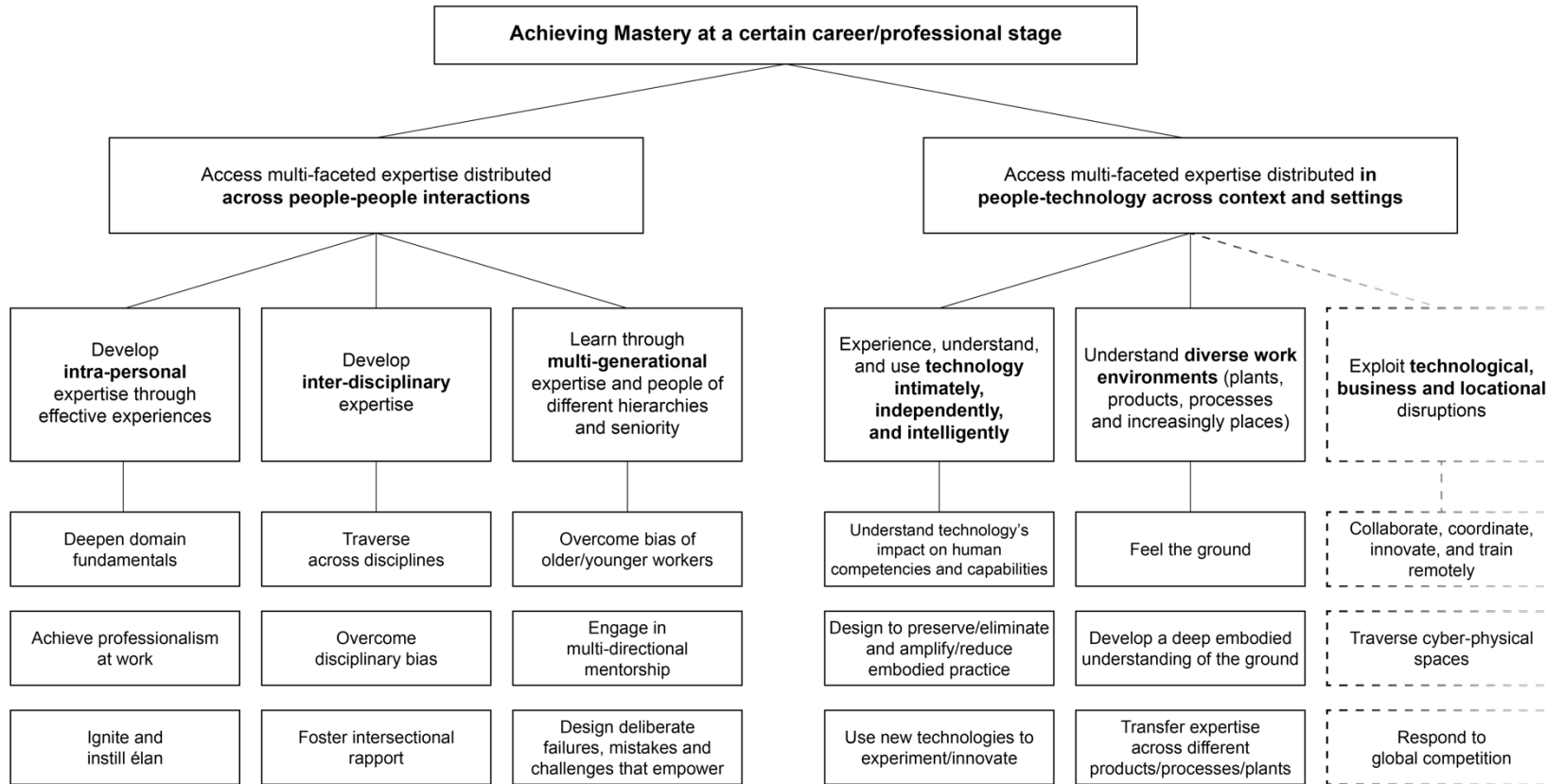
#### 6.1 **Design a Multi-faceted Mastery Model to guide the development of deep, distributed, and multi-faceted expertise in the digital age**

The ladder model of expertise with its step-by-step progression, one-to-one human-machine relationship, and hard division of labour has fallen behind extant literature and the realities of the modern workplace.

We need a new model that reflects the modern workplace's many-to-many networks between humans and machines, and where the division of labour is fluid. The new model must also reflect how technical professionals coordinate and collaborate across diverse people and disparate technologies, and how well they do so reflects how deep and wide their expertise is.

We thus propose designing a new Multi-faceted Mastery Model based on our findings. A first design of the Multi-faceted Mastery Model is presented below. (Figure 7)

Figure 7: Multi-faceted Mastery Model



This Multi-faceted Mastery Model incorporates the ladder model and what is in extant literature through the leftmost branch focusing on intra-personal expertise.

The model then integrates them with our new understanding of mastery from our research findings – these are found in the other five branches to the right. The sixth branch is in dotted lines as it is still evolving (due to the pandemic) but is nonetheless an important lens into the nature of future mastery.

All six branches are then grouped according to whether they are about people-people interactions or people-technology interactions. These two categories account for how expertise is now distributed across a multiplicity of people and technologies.

The model's depth and breadth gives it the versatility to embrace the distributed and multi-faceted nature of expertise in the digital age. That versatility also means that it can be integrated into Singapore's current and future policies and investments in skills, learning, education, and training. The model can also guide the development of deep expertise in workplaces, continuing education and professional development programs as well as institutes for higher learning. The skills investments can then become more targeted to sharpen the Singaporean workers' competitive edge. The Singapore workforce is thus more likely to thrive, transform, and stay on top of disruption, and less likely to struggle in keeping up with business, technological and locational changes.

We will show how such targeted interventions can be designed in the recommendations that follow and also explain the value of each specific recommendation.

## 6.2 **Design targeted interventions (initiatives, incentives, and guidelines) for different dimensions of mastery in professionals**

The Multi-faceted Mastery Model is based on the practical experiences of our participants. They shared with us their strategies for developing mastery, which we worked into the model as different individual dimensions. Hence the individual dimensions are also actionable interventions that target a specific area of mastery.

Technical professionals, companies, Institutes for Higher Learning, and government agencies can pick and choose different dimensions in the model according to their needs. For example, they could “design deliberate failures” to enhance their in-house training, and “design to preserve/eliminate and amplify/reduce embodied practice” to improve technological investment decisions. In doing so, they can also draw inspiration from the concrete examples featured in the quotes, fieldnotes, and literature review found throughout this report.

Technical professionals, companies, Institutes for Higher Learning, and government agencies can also develop additional interventions.

For example, companies can consider developing checklists to ensure they “experience, understand, and use technology intimately, independently, and intelligently” by examining how they fare in the three different areas that constitute this dimension.

Companies can also consider modifying their existing mentorship initiatives to ensure their employees “engage in multi-directional mentorship”. This would include identifying new pairings between employees across different generations and training them in the skills needed to “overcome bias of older/younger workers”. They can also create safe intersectional spaces where employees “foster intersectional rapport” and “overcome disciplinary bias”.

Institutes for Higher Learning can explore where “design deliberate failures, mistakes, and challenges” are the most “effective experiences” for students and adult learners to “develop intra-personal expertise”. They can then train their trainers to deliver such experiences in both pre-employment training (PET) and continuing education and training (CET), so that their students and adult learners can accelerate their expertise through the “concentrated efforts” (see chapter 3) that these experiences demand.

Government agencies, together with its tripartite partners (e.g., the unions) can publish guidelines and provide incentives aimed at these targeted interventions. These would be similar to existing guidelines such as those on job redesign in the age of Artificial Intelligence, second job arrangements, and risks of remote work, as well as existing skills upgrading subsidies and digital transformation incentives.

The effectiveness of all of these targeted interventions can be subsequently assessed using surveys and other similar tracking mechanisms, which we will outline in the next recommendation.

### 6.3 **Track professionals’ progress of mastery over time and at seminal stages of their careers**

We can use the Multi-faceted Mastery Model to track the effectiveness of the targeted interventions discussed in the preceding recommendation. We can survey professionals before and after specific targeted interventions to assess their effectiveness. We can then improve those interventions to accelerate the development of mastery.

We can also survey technical professionals at seminal stages in their careers to track the progress of their expertise in their professions and workplaces. We can then use the results to pinpoint the practices – what, when, where – that are most likely to make an impact.

We can do this easily by adapting the approach used for tracking graduate outcomes (such as employment surveys and tracer studies). For example, we can survey technical professionals when they graduate, when they receive accreditation, and after a specific number of years in the workplace.

We show how we can go about doing this using the illustrative hypothetical examples below.

Take, for instance, the three diagrams below.

The graduating class of 2021 Polytechnic X’s CE and PE programs can be surveyed using the Multi-faceted Mastery Model out of a 5 point scale and the average results can be plotted against the national average. These graduates can subsequently be surveyed over the years to track their progress from ECT to MCT to ET, at the 0, 5 and 15 year mark respectively.

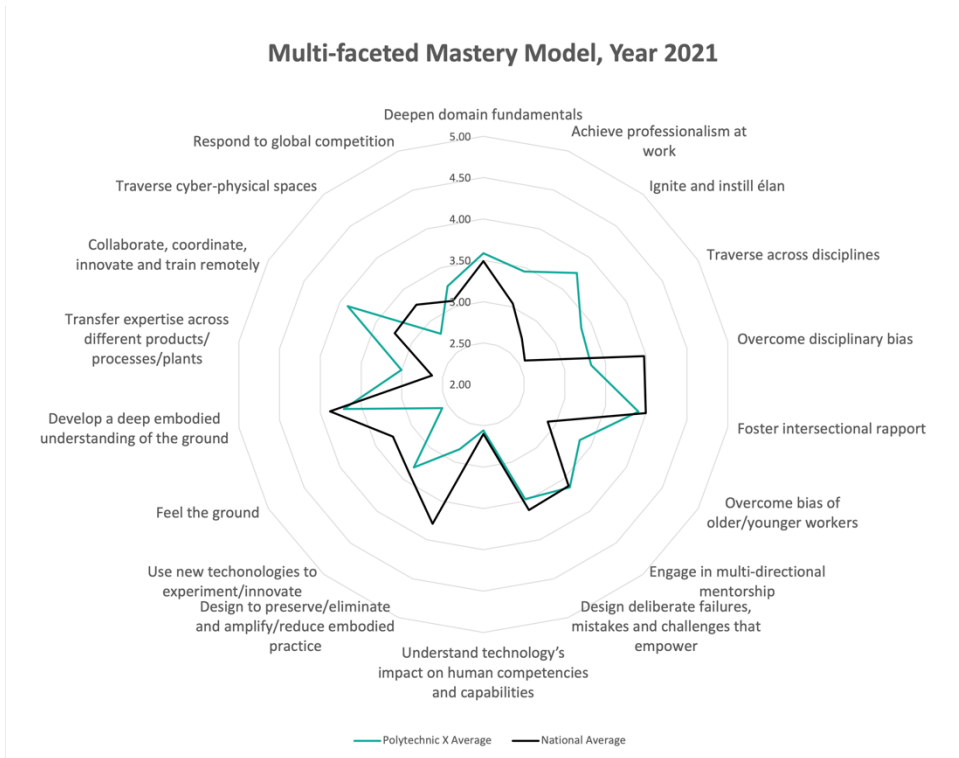


Figure 8: 2021 Multi-faceted Mastery Model Radar Chart for Class of 2021

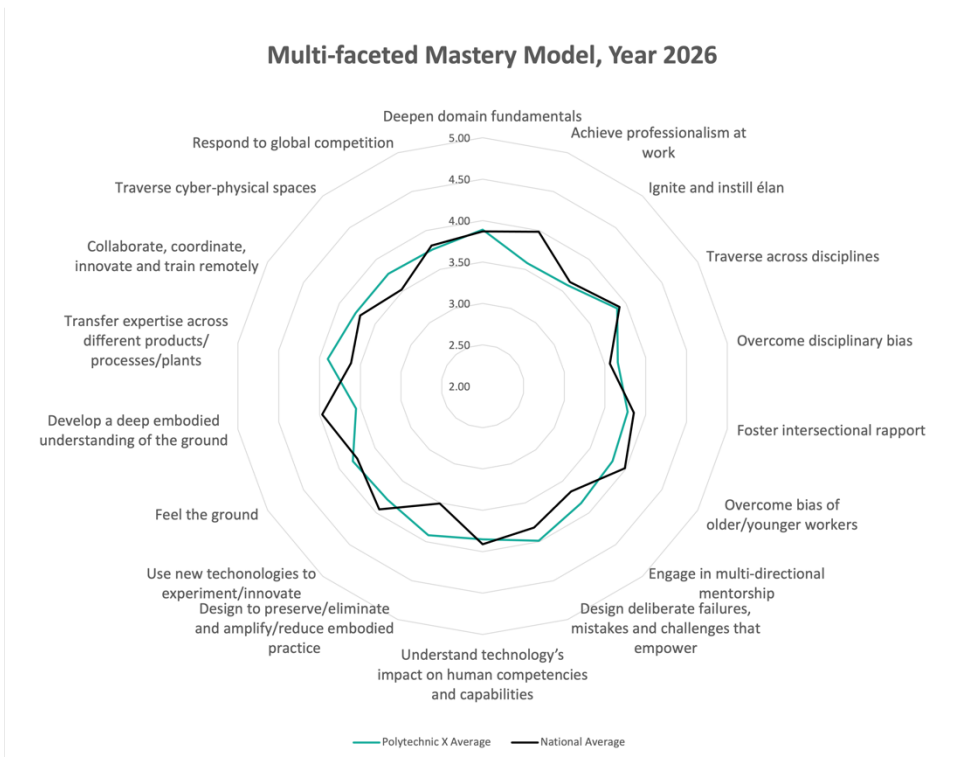
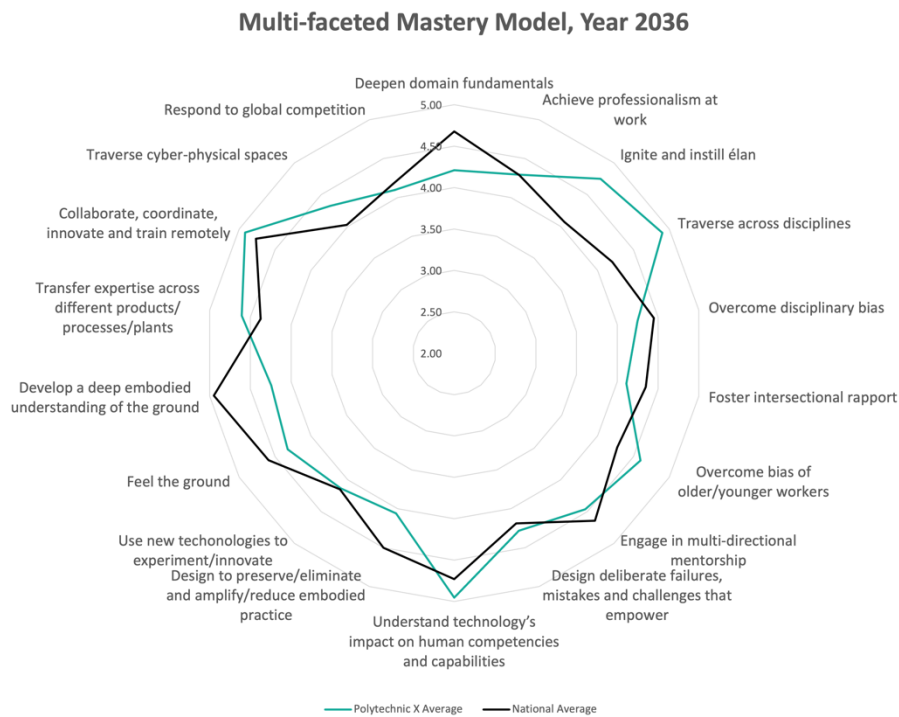


Figure 9: 2026 Multi-faceted Mastery Model Radar Chart for Class of 2021



**Figure 10: 2036 Multi-faceted Mastery Model Radar Chart for Class of 2021**

Moreover, as we pointed out in section 4.1, there is always a risk that the discourse on digital transformation may be skewed towards a techno-centric angle, where we look from the lens of technology determinism instead of human adaptability. We can make sure that there is adequate emphasis on the people and human adaptability dimension, by breaking down the model into both the people-people and people-technology dimensions. That deconstruction means that we can take a balanced perspective where we pinpoint the exact areas where the cohort is doing well and where it is lagging behind, as shown in the hypothetical illustrative examples below.

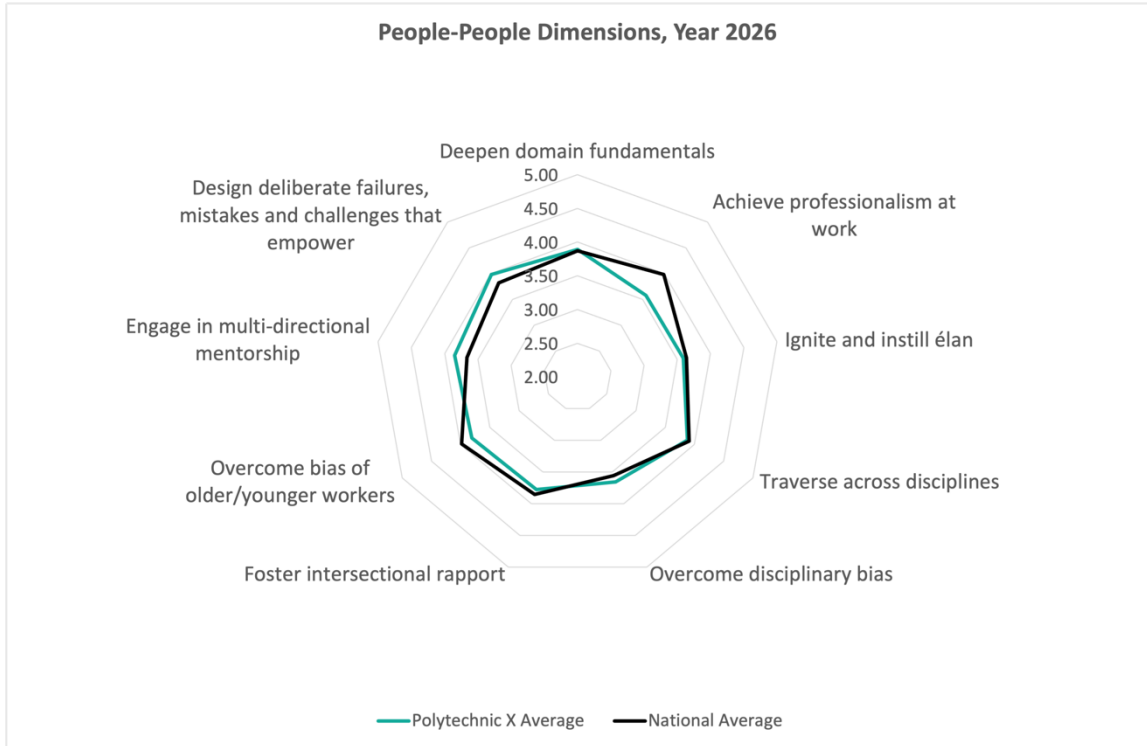


Figure 11: 2026 People-People Radar Chart for Class of 2021

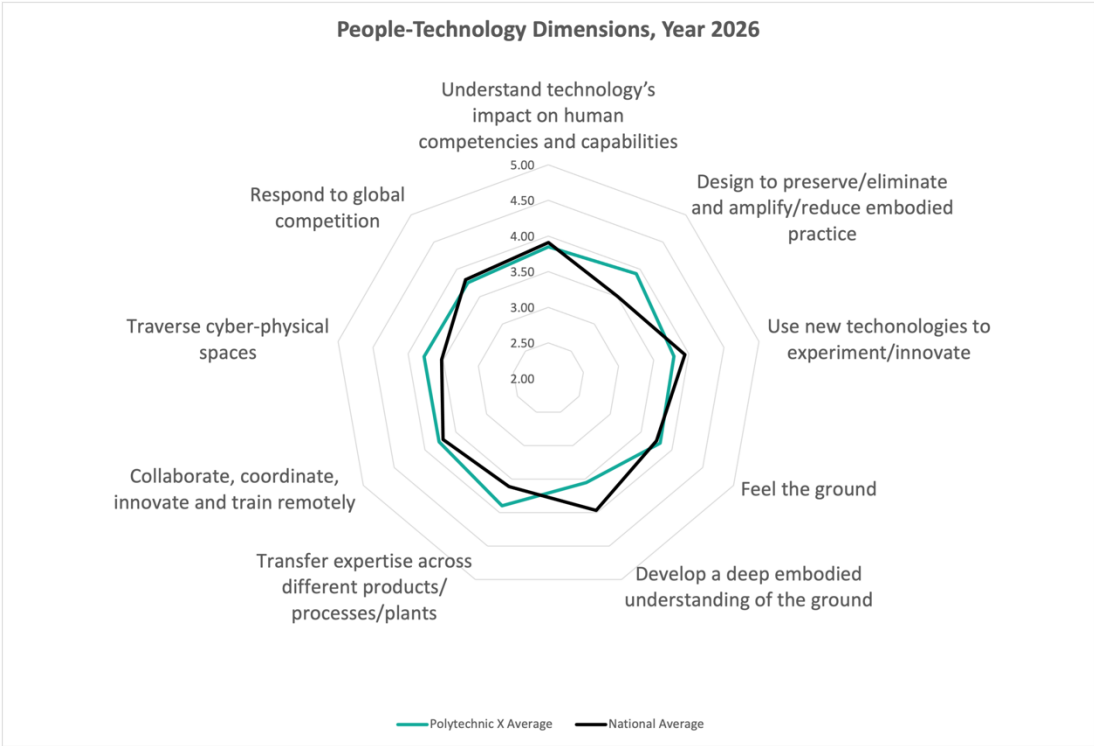


Figure 12: 2026 People-Technology Radar Chart for Class of 2021

Through in-depth analysis of the radar charts, training programs can be introduced for technical professionals at various stages in their careers to improve the particular areas they are weak in and to further strengthen the areas where they are doing well. This ensures that they are able to make steady progress attaining mastery in the digital age.

#### 6.4 **Establish keystone programs around keystone dimensions to cascade and accelerate the development of mastery in multiple dimensions**

We can develop interventions to target specific individual dimensions or small combinations of different dimensions (as described in recommendation 6.2). We can also establish programs that tackle large combinations of different dimensions or even all of them at the same time. We call these keystone programs, and they are designed around particular keystone dimensions.

We borrow the idea of keystone from the study of ecosystems. In ecosystems, a keystone species is a species on which the ecosystem disproportionately depends on. It has an outsized effect, and without it, the ecosystem could fall apart. Conversely, its presence holds the ecosystem together.

In mastery, the equivalent to the keystone species is what we have called the keystone dimension. It is the dimension of mastery which pulls along the other dimensions. Without it, the other dimensions would be compromised too, and the overall development of mastery is jeopardised.

Establishing a program around a keystone dimension thus has a cascading effect on the other dimensions. It accelerates the systemic development of mastery as a result.

The keystone dimension depends on the needs of the company or industry. Companies and industries can also take advantage of the Multi-faceted Mastery Model's versatility (see recommendation 6.1) to both diagnose and assess what their keystone dimension is, and to create the keystone programs around it.

#### **Example: Safety and designing deliberate failures and mistakes towards success that make the invisible visible, and nurture care not fear**

We illustrate how such keystone dimensions can be determined, and how such keystone programs can be designed with an example on safety in the CE sector.

Safety is paramount in the CE sector. Consequently, failures and mistakes in operations must be avoided at all costs. That in turn points to the mastery dimension of "Design deliberate failures, mistakes, and challenges that empower" as the keystone dimension.

Why is this so? It is because to succeed at safety, we must make fewer mistakes, and we only make fewer mistakes if we have made more of them.

This can be understood as follows. On one hand, manufacturing strives to have zero failures and mistakes, because they could be disastrous. On the other hand, as professionals ranging from students to experts stressed in section 3.2B, they learn the most when failures and mistakes happen, and they have to troubleshoot them. This is because such events have a centre of gravity that pulls all the other dimensions of mastery into its orbit. They make the invisible people-people and people-technology interactions visible. They leave an indelible mark on individuals where the professionals not only remember details of the event more clearly but also contribute greater value to their overall learning compared to other

experiences. They also test technical professionals' grasp of domain fundamentals, depth of understanding of the issue at hand, and ability to transfer what they know into crisis settings.

In other words, technical professionals strive to reduce failures and mistakes. However, to reduce them, they also need to make enough of them to be able to do so. Throw into this mix how effective failures and mistakes are able to build mastery, and how reducing them can reduce opportunities to develop mastery, and we have a conundrum on our hands.

The way to resolve this is thus to “design deliberate failures, mistakes, and challenges that empower” into how we train and learn in the workplace and in school. We can use the ways outlined earlier in our report, build on them, and further enhance them in three ways.

The first is to explicitly design the other dimensions around it, so that they are incorporated and integrated into learning, training and education. This cascading effect of the keystone dimension onto the other dimensions means the latter will also be targeted.

The second is to ensure this goes beyond an one-off intervention, to become a sustained and substantial part of workplace learning, education, and training. Companies and Institutes for Higher Learning for example, could increase the weightage of such designed failures, mistakes, and challenges into their learning and training curricula.

Thirdly, companies and Institutes for Higher Learning must develop new skills to design such experiences. New skills are needed because such experiences must empower. Otherwise, constantly failing and making mistakes - even if it is only in learning and training – can be enervating, demotivating, and disempowering. The failures and mistakes could be designed to lead to concrete and uplifting success at a later stage (which is after all the intention). These could in turn be made clear to technical professionals so that they know their failures and mistakes are a step forward in their mastery journey, and not a step back. New “seriously fun” pedagogies could also be developed. And all of these could be tracked for effectiveness as per what we have discussed in recommendation 6.3.

#### 6.5 **Gamify mastery to sustain motivation for the mastery journey and to encourage professionals to stay in the industry**

Achieving mastery at any stage of a professional's career takes time and tenacity. It is a marathon not a sprint. Staying motivated is key, but can be hard, even for the most dedicated.

We can help technical professionals stay motivated by helping them see the progress they are making. We can do this by gamifying the mastery journey using the Multi-faceted Mastery Model. We illustrate how this can be done with the hypothetical gamification checklist below.

As shown in figure 13, at Company X, an engineer and technician must work as a team to perform five tasks as part of their work.

These tasks can intersect between the two of them (i.e., their people-people interactions), and with the technologies they use (i.e., the people-technology interactions). Hence, progress on the mastery journey here is more than each of them becoming better at their tasks. It specifically focuses on interactions and the purpose is to incorporate the intersections at which mastery is distributed, i.e., in the people-people and people-technology interactions described in the report. This determines the invisible-visible loops that they will have to traverse with each other and with technologies in their work.

To perform these tasks, they will need different dimensions of mastery from the model. To perform each of these tasks to the highest standard (e.g., quality of output, or time taken etc), they will ideally have the highest level of mastery in each of the different dimensions of mastery – all the colours of the dots should be in gold i.e., analogous to the “gold standard”.

In reality, they will likely be still making progress towards this gold standard. This is where their current level can be silver or bronze. Once the current state is mapped and assessed, both the technician and engineer, as well as their company, can determine where they can enhance their expertise individually, together, or with others in the company. This can be through formal training, on-the-job training, mentoring, online learning and other means.

As they make progress, the colours can change to mark that progress, and they can earn rewards and recognition that motivate them on their mastery journeys. These rewards and recognition need not be monetary. They could be earned and tracked like the system of professional development points found in many professions. The crucial difference is they are gamified to keep professionals striving for the next level of expertise.

## Company X Tasks



● Bronze     ● Silver     ● Gold

**Engineer Y**  
 2 Years  


**Technician Z**  
 40 Years  


Deepen domain fundamentals	4		5	Deepen domain fundamentals
Achieve professionalism at work	1		1	Achieve professionalism at work
Ignite and instill élan	3		2	Ignite and instill élan
Traverse across disciplines/professions	5		3	Traverse across disciplines/professions
Overcome disciplinary bias	4		4	Overcome disciplinary bias
Foster intersectional rapport	2		2	Fostering intersectional rapport
Overcome inter-generational bias	1		1	Overcome inter-generational bias
Engage in multi-directional mentorship	1		5	Engage in multi-directional mentorship
Design deliberate failures, mistakes and challenges that empower	4		3	Design deliberate failures, mistakes and challenges that empower
Understand technology's impact on human competencies and capabilities	5		1	Understand technology's impact on human competencies and capabilities
Design to preserve/eliminate and amplify/reduce embodied practice	3		4	Design to preserve/eliminate and amplify/reduce embodied practice
Use new technology to experiment/innovate	5		5	Use new technology to experiment/innovate
Feel the ground	2		4	Feel the ground
Develop a deep embodied understanding of the ground	4		4	Develop a deep embodied understanding of the ground
Transfer expertise across different products/processes/plants	3		1	Transfer expertise across different products/processes/plants
Collaborate, coordinate, innovate, and train remotely	3		2	Collaborate, coordinate, innovate, and train remotely
Traverse cyber-physical spaces	2		3	Traverse cyber-physical spaces
Respond to global competition	2		5	Respond to global competition

**Figure 13: Gamified Mastery Checklist**

There are other additional ways to take advantage of this gamification checklist. Company managers could map the work that needs to be done to the most appropriate levels of mastery found amongst their technical professionals (e.g. identifying who can do an urgent task). Workers who are still “*levelling up*” for certain dimensions can also be assigned tasks suitable to help them level up. Tasks which require workers from different generations and seniority to collaborate can be supported with efforts in multi-generational mentorship, which helps to accelerate the process of attaining mastery for everyone.

Moreover, gamification would be particularly useful for specific segments of professionals who struggle with motivation. These include:

- 1) CE and PE students in Institutes for Higher Learning for whom their current course of technical/engineering study is not their top choice, and could even have been their last choices;
- 2) Current professionals who no longer see a future in the industry due to reasons ranging from pay to prospects.

Gamification can give them a sense of progression and achievement. This in turn gives them and their managers, companies, and schools some time to explore how to make it all work out for them. This hopefully reduces the leakage of trained professionals out of the respective sectors.

## 6.6 Hack the digital age to accelerate mastery for the digital age

In recent years, discourse surrounding mastery has placed a disproportionate emphasis on adopting advanced technologies such as data science, artificial reality (AI), and virtual reality (VR) for operations and for training.

As we saw in chapter 4, over-emphasis on adopting the most expensive latest technology may be at odds with how technologies are actually used effectively on the ground. It also risks overlooking valuable opportunities to hack the many digital technologies that are already affordable, widely used, and easy to use.

Our earlier findings on the use of the widely available Go-Pro camera to capture and share tacit knowledge is an excellent example (see section 4.1C). It can be used simply by attaching it to the head and recording what the expert does and says from the expert’s eye view. This was all that was needed to achieve a superior workplace learning outcome that can speed up mastery.

In fact, technologies that can create such superior outcomes can even be plain old boring technologies. We touched on the use of Excel to improve accountability and professionalism in section 4.1C. We also saw the use of styrofoam, corrugated cardboard, and pen knives to create customisable toolboxes that simplified and standardized work so that workers could achieve superior performance and subsequent mastery.

There is thus a latent opportunity to explore how everyday technologies can be experimented and innovated with to accelerate mastery (in addition to the conventional emphasis on building mastery in advanced technologies). These can be explored using existing efforts in design thinking, hackathons, internships, and industry collaborations with Institutes for Higher Learning.

These explorations could be based on the different dimensions in the Multi-faceted Mastery Model. For example, we could explore how simple signages and QR codes could be used in

different locations of the plants to deepen the professionals' awareness and appreciation of the fundamentals needed at these different locations. We could also explore how user interfaces of technologies could be re-designed to closely mimic the sensory experiences critical for mastery. As one of our focus groups discussed, such re-designs could be the outcomes of co-designing and collaborating with experienced technical professionals, so that their experiences and knowledge could be incorporated to benefit the next generation. This could improve talent development, knowledge retention, and sharing within companies as well.

Other explorations could look into what the pandemic has accelerated (chapter 5). We could be experimenting with existing communication platforms to improve collaboration processes and to create new ones, while developing a more complete picture of their possibilities and limitations so that we have a more intimate, independent, and intelligent understanding and use of them in future.

At this juncture, it is also important to note that experimenting and innovating with technologies is in fact one of the dimensions in our Multi-faceted Mastery Model. In that respect, what we have described in this recommendation goes beyond being smart about the full range of possibilities for technologies old and new. It is also an example of recommendation 6.4 where "Experimenting/innovating with new technology" is now the keystone dimension, around which a keystone program can be designed so that the explorations have a cascading effect on the other dimensions of mastery.

#### 6.7 Upgrade pilot plants into 'petri-dishes' for future mastery

Chapter 5 makes clear that mastery will evolve with technological and economic shifts. Incorporating these shifts however poses a challenge for companies and professionals. They need to run current operations smoothly and safely, making it hard to test and integrate these shifts. The risk then is that a gap opens up between current mastery and future mastery.

We thus propose upgrading the pilot plants found in Institutes for Higher Learning and in companies into "petri-dishes" for future mastery in both the CE and PE industries. Unlike many current pilot projects and testbeds which are technology-centric, these upgraded pilot plants will focus on interactions, especially the people-people and people-technology interactions needed for future mastery. Instead of emphasising technology adoption and determinism, we emphasise what is needed for human adaptability (see also our discussion in section 4.1).

In addition, pilot plants are cheaper and more flexible as they can be updated more frequently to keep pace with developments, compared with existing plants where there is path dependency in what people can practice and develop within the existing setup.

These upgraded pilot plants would take the different dimensions of mastery as they evolve, test them, and explore what would be needed to incorporate them into existing embodied practice. They would be 'petri-dishes' for future mastery that make the invisible aspects of mastery 'visible' and use an element of playful experimentation to help companies and professionals innovate with new interactions that speed up the process of attaining future mastery.

For example, the pilot plant can act as a safe intersectional space for technical professionals of different generations to interact and practice multi-directional mentorship. In the workplace, there are often organisational hierarchies involved which can bring in generational biases as explained in section 3.3A. Pilot plants can act as a space to get people to start practicing communication skills that encourage inter-generational learning as everyone is given the same

identity of “student”, regardless of age, job position or experience. They can also be a space where companies test aspects of their change management initiatives so that they can make informed improvements during the actual implementation of those initiatives. Our findings gathered that professionals are most receptive to change and the introduction of new technologies or ways of working when they are being informed in advance, educated about the different functions in a detailed manner and also given sufficient time to adjust and pick up new skills required. This process is usually spearheaded by change management teams at companies and we find it beneficial to incorporate this element into the pilot plant.

This can also be useful for research. While in-depth studies have been done on social learning in the workplace, there is a lack of literature on inter-generational mastery. The use of a pilot plant will thus also provide us with an opportunity to further research into how inter-generational mastery and social development of skills are developed through peer interactions with team members of varying experiences and skill competencies. We believe that this would allow us to see how the development of mastery and skills development flows both ways, and how experienced technicians are still learning and developing new skills sets while imparting knowledge attained from years of experience to their junior counterparts at the same time. Novice technicians can also step up to share knowledge about new technologies that they may be more familiar with and how they can be used to complement knowledge and experiences by experienced technicians. This serves to make mastery more tangible for all through active communication and experimentation.

Doing so would turn what is commonly seen as bug in the Institutes for Higher Learning into a feature and an asset for Singapore. Institutes for Higher Learning normally invest in new technologies to ensure that students trained are prepared for the industry. This sometimes leads to a situation where students are trained too far ahead of prevailing practice as the industry's speed of digitalisation may be slower than that of schools. This was evident in our field work whereby the technologies used in the pilot plant included Virtual Reality Goggles, whereas interviews with CE professionals revealed a much slower uptake of said new technologies. Since Institutes for Higher Learning have more leeway in experimenting/innovating with new technologies and interactions for educational purposes, working professionals can immerse themselves in experiences that will inform them what these new interactions and technologies might mean for future mastery and their current ways of working. They will be better able to develop a more intimate, independent, and intelligent feel and understanding of technology. As a result, and they are also able to do so in a safe space as schools are recognised as safe spaces to learn and make mistakes in comparison to the workplace, as the associated risks and costs are much lower than the working world. Students and professionals can also develop new skills for interacting with each other through new and existing technologies such as sensors, IoT and even corrugated cardboard. They can co-design new innovations and interactions needed for current, continued, and future mastery.

Moreover, we also see the possibility of using these pilot plants to attract investments. In conversations with members of the industry, we were told that companies often hesitate to invest in digital transformation because it can come across as complex, and in other cases because the large budgets needed can only be approved by their HQs, often in another country. Pilot plants can simplify these complexities sufficiently by concretely showing the potential benefits that can be reaped from investing in certain technologies and thus encourage them to do so. These can in turn be showcased to HQs overseas to demonstrate the advanced operating possibilities and workforce competencies in Singapore. Given what the pandemic has demonstrated with remote possibilities, this showcase can even be done through a remote show/demonstration/streamed live to CEOs and decision makers sitting in the HQs, to increase the odds that they will approve the decisions and budgets for investing in the workforce here.

This can help establish Singapore's status as a suitable global and regional HQ for Multinational Corporations (MNCs) that have or are planning to set up operations in Asia. The pilot plants act as a physical proof of what new interactions and technologies are capable of, and the work-ready workforce who can engage in these interactions and operate these technologies. As a result, companies might be more willing to test and develop new and novel ways, such as enhancing remote work, and this attracts a steady supply of future financial investments for Singapore to stay ahead.

Overall, upgrading pilot plants into 'petri dishes' for future mastery will train students and professionals alike to be masters of the 4IR. They will constantly be ahead of the curve to ensure that the workforce stays on top of disruption, further strengthening Singapore as a key player in the global economy.

## 7. Mastery for all Ages

Our research findings and recommendations point to a hopeful vision for what mastery in the digital age would look like in Singapore's future.

All age groups will be able to achieve the mastery they need at different stages of their professions and careers. They will be able to do so because different age groups will be able access, incorporate, and integrate the expertise that is distributed across all of them. They will design experiences for each other that make what is visible to each of them but invisible to others, visible to others. They will teach, mentor, encourage, inspire, and learn from each other, on top of pursuing their own individual upskilling and reskilling.

These age groups will also be able to achieve mastery as the expertise evolves with new Ages in technologies. We might be in the age of Artificial Intelligence and Industry 4.0 now, but this will shift and tomorrow might see an *Age of Quantum Computing* or Industry 5.0. Professionals will be able to adapt because they will be able to traverse and collaborate across different disciplines as well as across the cyber-physical. They will have developed the expertise to use new and old technologies to sharpen human senses, innovate, and work remotely, and these would be transferable across different work settings.

All age groups would also be equipped to sense future ages. Through keystone programs, future mastery pilot plants, and deliberate failures/mistakes/challenges, professionals will develop the acumen to spot, diagnose, and respond to crisis, competition, and changing industry conditions. They will be able to sense the invisible future that has yet to come over the horizon, or if the *“future is already here [but] it's just not very evenly distributed”*<sup>9</sup>, they will be able to find where this future is already visible.

Whatever this future brings, Singapore will be ready because we will have achieved mastery for all ages.

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<sup>9</sup> Quote by William Gibson

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# Appendix

## Annex A: Interview Guide (Students and Interns)

### Introductory questions (10 mins)

1. Tell me a bit about yourself
  1. Age, education, experience, current function and organisation
  2. Nationality
2. Why did you choose to do what you do?
3. Educational background?
  1. Ask about their original background
  2. Perhaps add a point about how they got to where they are
  3. Earn and learn, PCP, SkillsFuture? Workplace training?

### Main content (40 minutes) – Education & Work Experiences

#### EDUCATION (COURSEWORK AND INTERNSHIP)

4. What course(s) did you pursue in ITE / Polytechnic / University? (whichever applicable)
  - a. Why did you choose to pursue this course?
  - b. What was the curriculum like?
  - c. What were your expectations in the beginning when you started the course?
  - d. Did it meet / exceed / did not meet your expectations? Why? Or how so?
  - e. If you could improve the course in order to suit the work (in the industry), what would you change or add etc?
5. Did you have to do an internship?
  - . How long was it?
  - a. What did you do during the internship?
  - b. Was it a good experience in learning about the work in the industry?
  - c. Based on your experience, did you feel prepared for working in the job and industry? What helped or did not help?
  - d. What type of skills did you get from the course and from the internship? What skill sets would be useful for the workplace? How do you think you can get these skills?
  - e. What would you change about the course or internship (*whichever aspects that applies*)?
6. Did you pursue further education in the same industry upon completion of your course? Or did you start working?
  - . Why did you decide on doing so (*either study or work*)? – **Proceed to question 7 if interviewee pursued further studies or proceed to question 9 if interviewee opted to work.**
7. What course did you pursue and where?
  - . What made you decide to pursue this course?
  - a. What was the curriculum like?
  - b. What were your expectations in the beginning when you started the course? Did the course enhance your existing knowledge and skills?
  - c. Did it meet / exceed / did not meet your expectations? Why and how so?
  - d. If you could improve the course in order to suit the work (in the industry), what would you change or add etc?
8. Did you have to do an internship as part of this course?
  - . How long was it?
  - a. What did you do during the internship? Was it any different from the past internships?
  - b. Was it a good experience in learning about the work in the industry?
  - c. Based on your experience, did you feel prepared for working in the job and industry? What helped or did not help?
  - d. Can you walk us through, step-by-step, what you do in a regular shift during your internship?
  - e. With whom do you collaborate and communicate mostly during a regular shift?
  - f. Can you give an example of a shift or event that was very different from a regular shift?
  - g. Are all shifts more-or-less similar?
  - h. Has your work been impacted by the COVID-19 outbreak? If so, how?

- i. What type of skills did you get from the course and from the internship? What skill sets would be useful for the workplace? How do you think you can get these skills?
- j. What would you change about the course or internship (whichever aspects that applies)? = **Proceed to question 11 onwards – SKIP questions 9 and 10.**
- 9. Can you tell us what goes on in your place of work?
  - . What does your company do?
  - a. What does your division/plant do?
  - b. Have you always worked in this area/division or have you ever had experiences working in other divisions of the organisation?
    - i. If yes, in what ways are these similar or different?
    - ii. What was the transition like (if any)? Were you required to undergo additional training? If so, what was that like or how was it conducted?
- 10. What do you do as a [insert occupation here]?
  - . **[Activity]** As we rarely get a chance to see a plant, can you sketch the plant / where you work and perhaps give us a brief idea about it?
    - a. Can you walk us through, step-by-step, what you do in a regular shift?
    - b. With whom do you collaborate and communicate mostly during a regular shift? What are some of the practice(s) that you think are most important for [occupation]?
    - c. Are all shifts more-or-less similar?
    - d. Can you give an example of a shift or event that was very different from a regular shift?
    - e. With the current situation (outbreak), has it affected you in terms of your work?
- 11. At work, who are some of the individuals/colleagues that you work closely with? How are they related to your own work?
- 12. Are there individuals in the workplace that you look up to? Learn from? If so, who are they, why do you look up (or aspire to be?) like them/him/her?
- 13. Based on your experience, what distinguishes a mediocre technician from an expert or master technician? (What is it about them that makes them perceived to be an expert or master technician/engineer?)
  - . What does an expert/master do differently?
- 14. Can you identify what are some skill sets that you think you are using over the course of the day?
  - . Where and how did you learn them?
  - a. How did you know what to do with them? (*How do you know how to apply them?*)

## **DIGITALISATION**

- 15. What are some forms of digitalisation you have noticed in your workplace?
  - a. In what ways have you experienced digitalization in your area of work? And what is your opinion of these digitalization efforts?
  - b. Do you interact with them often?
  - c. How have these tools changed the way you do work?
  - d. Was it easy/hard to adapt? Why is that so?
- 16. What do you think plants of the future will be like?
  - . Where do you see yourself in the future? (*For example, in terms of occupation/position and the work tasks*)
    - a. Do you think you are ready for work in those plants? (*Factors that can help or hinder*)
    - b. Do you think that the skills in demand will change over time? If so, in what way?
    - c. What would be the best way to remain relevant as the industry experiences changes over time?
- 17. What are some challenges that you think the industry will face in the future?
- 18. What do you think potential students and technicians should learn or do in order to be prepared for work in the industry?
- 19. What advice would you give to someone entering this industry?

### **End: (10 mins)**

- 20. Where do you see yourself in the future?
- 21. Are there any questions that you think we should be asking?
- 22. Do you have anyone else that we can contact?

## Annex B: Interview Guide (ECT and MCT)

### Introductory questions (10 mins)

1. Tell me a bit about yourself
  1. Age, education, experience, current function and organisation
  2. Nationality
2. Why did you choose to do what you do?
3. Educational background?
  1. Ask about their original background
  2. Perhaps add a point about how they got to where they are
  3. Earn and learn, PCP, SkillsFuture? Workplace training?

### Main content (40 minutes)

#### Tasks/Skills/Learning

4. Can you tell us what goes on in your place of work?
  - a. What does your company do?
  - b. What does your division/plant do?
  - c. Have you always worked in this area/division or have you ever had experiences working in other divisions of the organisation?
    - i. If yes, in what ways are these similar or different?
    - ii. What was the transition like (if any)? Were you required to undergo additional training? If so, what was that like or how was it conducted?
5. What do you do as a technician/engineer?
  - . **[Activity]** As we rarely get a chance to see a plant, can you sketch the plant / where you work and perhaps give us a brief idea about it?
    - a. Can you walk us through, step-by-step, what you do in a regular shift?
    - b. With whom do you collaborate and communicate mostly during a regular shift?
    - c. Are all shifts more-or-less similar?
    - d. Can you give an example of a shift or event that was very different from a regular shift?
    - e. With the current situation (COVID-19 outbreak), has it affected you in terms of your work?
6. Can you identify what are some skill sets that you think you are using over the course of the day?
  - . Where and how did you learn them?
    - a. How did you know what to do with them? (*How do you know how to apply them?*)
    - b. Have you had to pick up new skills or learn to do things differently due to the changes as a result of the COVID-19 outbreak? If so, what are some of these?
7. At work, who are some of the individuals/colleagues that you work closely with? How are they related to your own work?

#### Expertise/Mastery

8. Are there individuals in the workplace that you look up to or learn from? If so, who are they, why do you look up (or aspire to be?) like them/him/her?
9. Based on your experience, what distinguishes a mediocre technician from an expert or master technician?
  - a. What does an expert/master do differently?

#### Digitalisation

10. What are some forms of digitalisation you have noticed in your workplace?
  - a. In what ways have you experienced digitalization in your area of work? And what is your opinion of these digitalization efforts?
  - b. Do you interact with them often?
  - c. How have these tools changed the way you do work?
  - d. Was it easy/hard to adapt? Why is that so?
  - e. What are some of the additional or new skills that are needed as work becomes more digitalised? How do you learn these new skills (if any)?
11. What do you think plants of the future will be like?

- . Where do you see yourself in the future? (*For example, in terms of occupation/position and the work tasks*)
  - a. Do you think you are ready for work in those plants? (*Factors that can help or hinder*)
  - b. Do you think that the skills in demand will change over time? If so, in what way?
  - c. What would be the best way to remain relevant as the industry experiences changes over time?
12. What are some challenges that you think the industry will face in the future?
    - . Potential (manpower, output)
  13. What do you think potential students and technicians should learn or do in order to be prepared for work in the industry?
  14. What advice would you give to someone entering this industry?

**End: (10 mins)**

15. Where do you see yourself in the future?
16. Are there any questions that you think we should be asking?
17. Do you have anyone else that we can contact?

## Annex C: Interview Guide (ET and Retirees)

### Introductory questions (10 mins)

1. Tell me a bit about yourself
  1. Demographic information: age, gender, ethnicity, nationality

### Main content (20 minutes):

#### Education

1. Can you share with us your education background?
  1. What course(s) did you pursue in ITE / Polytechnic / University? (*whichever applicable*)
  2. Why did you choose to pursue this course?
  3. What was the curriculum like?
  4. What were your expectations in the beginning when you started the course?
  5. Throughout your career, did you perhaps further your studies? (*Earn and learn, PCP, SkillsFuture? Workplace training?*)
  6. *If yes, what motivated you to do so? How did it affect your career (progression)? And if not, why not?*

#### Work Experiences

##### STARTING OUT

2. How did you choose to study/work in this industry?
3. How many years of experience do you have in this industry?
4. How did you start out? [*Studies or industrial attachment or work*]
5. What were some of the positions you have held over the years?
6. Can you identify what are some skill sets that you think you are using over the course of the day?
  - a. Where and how did you learn them?
  - b. How did you know what to do with them? (*How do you know how to apply them?*)
7. What were some of the main or notable changes that you observed and experienced?

##### WORK – TASKS, PEOPLE AND ENVIRONMENT

8. What do you do as a [*insert occupation here*]?
  - a. Can you describe what a plant is like?
  - b. Can you walk us through, step-by-step, what you do in a regular shift?
  - c. With whom do you collaborate and communicate mostly during a regular shift? What are some of the practice(s) that you think are most important for [*occupation*]?
  - d. Are all shifts more-or-less similar?
  - e. Can you give an example of a shift or event that was very different from a regular shift?
  - f. Has your work been impacted by the COVID-19 outbreak? If so, how?
2. Can you identify what are some skill sets that you think you are using over the course of your career?
  - a. Where and how did you learn them?
  - b. How did you know what to do with them? (*How do you know how to apply them?*)
  - c. Have you had to pick up new skills or learn to do things differently due to the changes as a result of the COVID-19 outbreak? If so, what are some of these?
9. At work, who are some of the individuals/colleagues that you work closely with? How are they related to your own work?

##### MASTERY / EXPERTISE

10. Based on your experience, how do you define someone to be a master or expert in their job? Does this change between then and now?
11. What distinguishes a mediocre technician from an expert or master technician? What does an expert/master do differently?

##### DIGITALISATION

12. Based on your experience over the years, what are some forms of digitalisation you have noticed happening in the workplace / industry?
- c. In what ways have you experienced digitalization in your area of work? And what is your opinion of these digitalization efforts?
  - d. Do you interact with them often?
  - e. How have these tools changed the way you do work?
  - f. Was it easy/hard to adapt? Why is that so?
  - g. What are some of the additional or new skills that are needed as work becomes more digitalised? How do you learn these new skills (if any)?
13. What do you think plants of the future will be like?
- a. Where do you see yourself in the future (*only relevant for those still working in the industries*)? (*For example, in terms of occupation/position and the work tasks*)
  - b. Do you think you are ready for work in those plants (*only relevant for those still working in the industries*)? (*Factors that can help or hinder*)
  - c. Do you think that the skills in demand will change over time? If so, in what way?
  - d. What would be the best way to remain relevant as the industry experiences changes over time?
14. Exit from the industry or Retirement - **[To determine at what phase the interviewee is in]**  
 . Reasons for leaving the industry or for retirement? **Proceed to questions 15 if the interviewee has retired.**
- a. **Only for those that switch to a different industry:** What made you switch to a different industry? What were the reasons?
  - b. How easy or difficult was it to adapt to the new job/industry?
  - c. How relevant (transferable) were the knowledge and skills that you had gained in the past to the new role/industry?
15. Prior to retirement, how did your role at work change? (*E.g.: Different job, less hours etc*)  
 . What was your experience like as you considered retirement? [Example: leading others, mentoring, chose to step down and take on different roles etc]
- a. Sharing of knowledge and experience – what are some of the ways, in your opinion, that you manage to share your knowledge and experience? [What other ways do you feel might be possible to continue sharing etc?]
16. What are some challenges that you think the industry will face in the future?
17. What do you think potential students and technicians should learn or do in order to be prepared for work in the industry?
18. What advice would you give to someone entering this industry?

**End: (10 mins)**

19. Are there any questions that you think we should be asking?
20. Do you have anyone else that we can contact?

## Annex D: Demographic Profiles of Participants (*Chemicals and Energy*)

No	Interviewee Code	Career Stage	Years of Experiences	Gender	Ethnicity
1	01	Student	-	Male	Chinese
2	02	Student	-	Male	Chinese
3	03	Student	-	Male	Chinese
4	04	Student	-	Male	Chinese
5	05	ECT	1	Male	Chinese
6	06	ECT	2	Male	Chinese
7	07	ECT	2	Male	Indian
8	08	MCT	4	Male	Chinese
9	09	MCT	4	Male	Chinese
10	10	MCT	10	Male	Malay
11	11	MCT	4	Female	Indian
12	12	MCT	15	Male	Malay
13	13	MCT	8	Male	Indian
14	14	MCT	12	Male	Chinese
15	15	MCT	4	Male	Chinese
16	16	MCT	NS	Male	Malay
17	17	ET	NS	Male	NS
18	18	ET	NS	Male	NS
19	19	ET	17	Male	Malay
20	20	ET	NS	Male	Malay
21	21	ET	15	Male	Indian
22	22	ET	40	Male	Chinese
23	23	Retired	5	Male	Chinese
24	24	Retired	40	Male	Chinese

## Annex E: Demographic Profiles of Participants (*Precision Engineering*)

No	Interviewee Code	Career Stage	Years of Experiences	Gender	Ethnicity
1	25	Intern	6 months	Male	Malay
2	26	Intern	6 months	Male	Other
3	27	ECT	1	Male	Chinese
4	28	ECT	3	Female	Malay
5	29	ECT	2	Male	Malay
6	30	ECT	2	Male	Malay
7	31	ECT	2	Male	Malay
8	32	ECT	2	Male	Chinese
9	33	ECT	2	Male	Chinese
10	34	ECT	1	Male	Chinese
11	35	ECT	2	Female	Indian
12	36	ECT	2	Female	Indian
13	37	MCT	6	Male	Chinese
14	38	MCT	6	Male	Malay
15	39	MCT	12	Male	Chinese
16	40	MCT	7	Male	Chinese
17	41	MCT	NS	Male	Malay
18	42	MCT	5	Male	Indian
19	43	ET	45	Male	Chinese
20	44	ET	15	Male	Chinese
21	45	ET	NS	Male	Chinese
22	46	ET	40	Male	Chinese
23	47	ET	40	Male	Chinese
24	48	ET	14	Male	Chinese
25	49	ET	30	Male	Chinese
26	50	ET	27	Male	Chinese
27	51	ET	15	Male	Chinese
28	52	ET	34	Male	Chinese
29	53	Retired	NS	Male	Chinese
30	54	Retired	42	Male	Chinese
31	55	Retired	40	Male	Chinese

## Annex F: Demographic Profiles of Participants (DFG DCHE Interns)

No	Interviewee Code	Institute	Year/Grade	Gender	Ethnicity
1	56	Polytechnic	3	Female	Chinese
2	57	Polytechnic	3	Male	Chinese
3	58	Polytechnic	3	Female	Chinese
4	59	Polytechnic	3	Male	Indian
5	60	Polytechnic	3	Male	Chinese
6	61	Polytechnic	3	Male	Malay
7	62	Polytechnic	3	Male	Malay
8	63	Polytechnic	3	Male	Malay
9	64	Polytechnic	3	Male	Malay
10	65	Polytechnic	3	Male	Chinese
11	66	Polytechnic	3	Male	Chinese
12	67	Polytechnic	3	Female	Chinese
13	68	Polytechnic	3	Male	Chinese
14	69	Polytechnic	3	Male	Chinese
15	70	Polytechnic	3	Male	Chinese
16	71	Polytechnic	3	Female	Chinese
17	72	Polytechnic	3	Male	Malay
18	73	Polytechnic	3	Male	Chinese
19	74	Polytechnic	3	Male	Malay
20	75	Polytechnic	3	Female	Indian
21	76	Polytechnic	3	Male	Chinese
22	77	Polytechnic	3	Female	Malay

### Annex G: Demographic Profiles of Participants (*Industry Experts*)

No	Interviewee Code	Career Stage	Industry	Gender	Ethnicity
1	78	ET	PE	Male	Chinese
2	79	ET	CE	Female	Chinese
3	80	ET	CE	Male	Others

## Annex H: Demographic Profiles of Participants (*Other Stakeholders*)

No	Interviewee Code	Career Stage	Years of Experience	Gender	Ethnicity
1	81	ET	32	Male	Indian
2	82	ET	20	Female	Chinese
3	83	ET	20	Male	Malay
4	84	ET	46	Male	Chinese

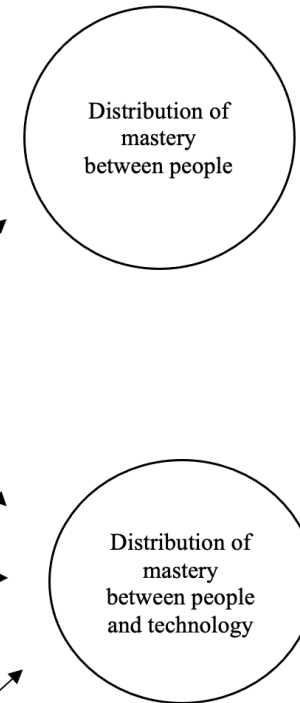
First-Order Categories

- Necessity of deep basic and ‘foundational’ skills
  - Attitude and passion as a motivational factor to become better
  - Learning the norms and values of a profession
  - Understanding and appreciating the interconnectedness in system
- The ability to traverse disciplines smoothly in day-to-day job
  - Appreciating diversity of disciplines on system and being aware of and overcoming disciplinary bias
  - ‘Safe spaces’ to experiment with ideas and where mistakes can be made
- Different generations have different kinds and levels of technological-and domain-expertise
  - Bi-directional mentorship and learning from different levels of expertise
  - Mistakes as an opportunity to deepen understanding of the system
- Technology can change human competencies (e.g. reducing or eliminating embodied practice)
  - Leadership choices regarding the impact of technology on competencies
  - Technology can also provide new/better ways of working
- Despite technological advancements, an expert engineer still requires a good understanding of the physical production process
  - Embodied understanding of physical/digital/hybrid work environments
  - Exposure to a greater variety of situations and work environments in order to promote transferability of skills
- Remote work, opportunities and challenges
  - Traversing physical, digital and hybrid workplaces
  - Issues regarding global competition (in the context of Covid-19 pandemic)

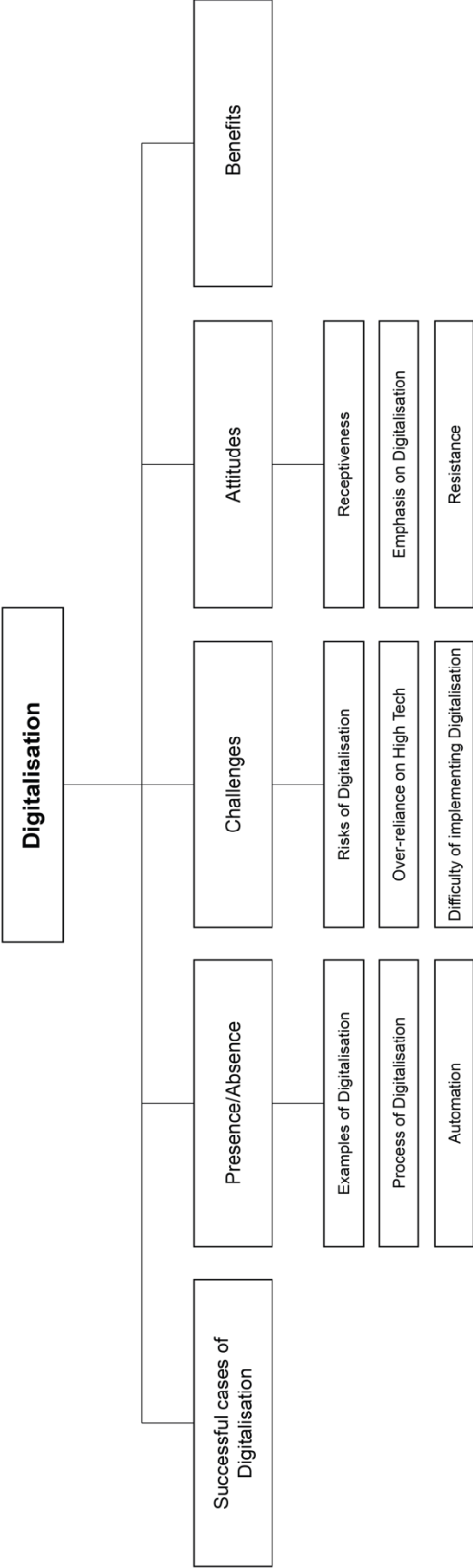
Second-Order Themes

- Developing intra-disciplinary expertise
- Developing inter-disciplinary expertise
- Learning from and between generations
- Understanding relations between technology and competency
- Understanding diverse work environments
- Exploiting disruption created by technology and the pandemic

Aggregate Dimensions



Annex J: Example of data structure around the concept of digitalisation



## Annex K: Empirical examples of main categories

### **Distribution of mastery between people**

Developing intra-disciplinary expertise

*“You were talking about AI la, Fintech la, all these things la. Ya we’re good in all these things but where is the basic fundamentals, basic foundations? There’s no basic foundations at all” – Precision Engineering, experienced technician*

Developing inter-disciplinary expertise

*“You can try and learn from your colleagues as much as you can. You have various departments. You have mechanical, you have electrical, your sales, your instrumentation, your control department. You learn as much as you can about them, and then you can upgrade your skills” – Oil & Gas, early career technician*

*Field note on traversing disciplines: “After [someone has] explained the issue to him, he understands and swiftly retreats back to his working space...He opens up his laptop [and] starts to type an algorithm into the software... He touches the robot before typing on his laptop again. Finally, he sat on the floor just beside the robot and began hacking into a couple of loose cables. He takes apart some of the components” – Observation at Cub Cleaner*

Learning from and between generations

*“[Talking about early career client interactions] Because you were more junior you would go to somebody who’s more senior and they would have the background to make sense of the conversation and lead the conversation while you are more in a listening mode” – Precision Engineering, experienced technician*

*“[Be] open to your seniors. You know your seniors are there to, they are there for a reason. They are called seniors for a reason. So go and learn from them, you know” –Oil & Gas, early career technician*

*“Typically, IT stuff, computer skills. They [younger technicians] are very good. So if I have any problems with a software, they will be the first person I talk to...I feel like a dinosaur when I’m talking” – Precision Engineering, mid-career technician.*

### **Distribution of mastery between people and tech**

Understanding relations between technology and competency

*“We call them Nintendo Engineers. Because basically they are just [working with technology] like playing a game” – Chemical Engineering, experienced technician*

*Field note on importance of the body in learning: “The work instructions look really complicated...the senior technicians beside him took the part from his hands and demonstrated the steps to assemble. As he tells him how to match the two parts before assembling them together, the younger technician is able to understand right away” – Observation at Box Builder*

*Field note on technology opening up new possibilities: “Through digitalization, it also meant that he had freed himself from manual, paper-based processes...he had more time to think about other work improvements” – Observation at Cub Cleaner*

Understanding diverse work environments

*“A refinery looks like a mini-city. And it’s very hard to understand if you’re not there...It’s very hard for me to solve [a problem] without going to the field and looking at the site” – Oil & Gas, experienced technician*

*“To level [my people] up, I’ll assign them a particular project where I think they need that kind of exposure...so it exposes them to the gaps in their competencies” – Precision Engineer, mid-career technician*

Exploiting disruption created by technology and the pandemic

*“Although this [digitalization] may contradict what we’re trying to do in the future, because the way we are moving towards is that, in the future, we are trying to reduce the number of people on site. We are trying to increase automation” – Oil & Gas, experienced technician*

*“I think for the next 10 years all the production will be getting fully automatic. So for the engineer side, I think programming will [become] important...how to program the machine to work with other machine” – Precision Engineering, mid-career technician*