Tomorrow's thinking.

Today's people.

A thoughtbook to reimagine the future of engineering, human-anchored with digital possibilities

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GHD digital

A collection of 38 perspectives, ideas and provocations that seek to address how might we:

/ prepare, equip and empower our future engineers for tomorrow's challenges?

/ reimagine the engineering vocation to be most impactful for engineers and the communities they serve?

/ most seamlessly and efficiently connect our increasingly sophisticated digital intelligence to the physical world?

/ empower engineers and non-engineers, to best use skills, interests and ambitions to think outside the square and affect positive change?

/ inspire budding engineers and others to demonstrate the mindset and skills our future needs?

Foreword

Throughout my varied career, I have had many dynamic conversations with professionals across numerous industries and viewpoints. I have always held the belief that I should enter every conversation prepared for my mind to be changed on a given subject.

After an exciting conversation, I reflect, analyse, decide, adapt and act accordingly. This ability to be agile and open has served me well personally and professionally and I feel privileged when I receive the same openness from another professional. This thoughtbook is, among other things, a celebration of the human quality of openness: a diverse group of people generously sharing their stories and experience in the hope that they can affect positive change to others in this rapidly changing world we are living in. Regardless of the contributors' industry, background or seniority, I suspect you will find a common thread, a fluidity in their viewpoints. This is not to say that everyone is of one mind or even agree with one another but they have bravely shared their insights in a multifaceted conversation about the future of the engineering profession in the new disruptive era. It is with great pride that I tell you the story of how this wonderful collection of perspectives came to fruition.

I was sitting in my office late one night (as you do) last year, deep in thought reflecting on the challenges of the engineering and construction (E&C) industry and the challenges my organisation will be facing in the near and distant future. This night came off the back of my leadership team's global strategy session, where we had discussed and debated our clients' expectations and how we can best position ourselves to help them in this era of the Fourth Industrial Revolution (Industry 4.0). While manufacturing, aerospace, professional and financial services industries lead the digitisation of work practices and assets, the E&C industry is amongst the least digitalised. A 2017 McKinsey report highlighted that with the low track record of technology adoption and major productivity challenges, the industry is a prime target for disruption. With more than 100 million people working in the global E&C industry, the socio-economic impact will be significant when this happens.

Having worked the majority of my career in management consulting, I now have the privilege of leading a global team of highly talented digital professionals backed by a global organisation with more than 90 years of engineering experience. When you consider the impact of engineers on the world since the First Industrial Revolution, they have made a vital, iterative contribution to the quality of life people now lead. Their impact is ubiquitous. I believe Industry 4.0 presents major opportunities for engineers to continue creating new sustainable value for the society and industries they support. By combining deep engineering expertise and their industry knowledge with digital technologies, engineers can enable us to reimagine and create a new future.

In this stream of consciousness, my thought and my belief (my belief from the beginning of story, if you remember) aligned. I was under no illusion that I was the only one interested or excited about the numerous opportunities that exist, as we contemplate the future of engineering and the vital contribution of engineers in the era of Industry 4.0. There are many distinguished and accomplished leaders from industry, academia, the arts and the humanities who are thinking about the future of the engineering discipline enabled by technology advancements and new ways of thinking. No doubt, all the leaders have a role to play in the future we are building. All of their perspectives and thoughts are valid and add a different nuance to how we approach Industry 4.0 and digital disruption. I wanted to provide a platform for their voices to be heard.

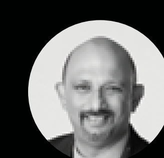
The idea of this thoughtbook was born. And I knew just the person to bring the idea into being. My colleague Jacyl Shaw, who heads our Digital Innovation practice, is quite a people person. If you've met her, you might say that's even an understatement. I knew that she would be the perfect connector to bring everyone together. Now, seeing the book in its final, polished form, I must offer my sincere thanks and gratitude to Jacyl and her team for their colossal effort in engaging our contributors across numerous industries and time zones and diligently editing their work to give us this wonderful finished collection of 38 perspectives about the future of engineering.

Having read all the pieces prior to publication, I can assure you (my bias aside) that you are in for an engaging and thought-provoking read. If you are a voracious reader, you may be inclined to read the entire collection in one sitting. If you'd rather pick and choose and read at your own pace and interest, you will find a guide of "How to use this thoughtbook" on the next page, which details how you might engage.

Out of all the many books, articles, and papers to read in the world, on this occasion, you have chosen this one and I sincerely hope it is worth your while. For my part, all I can say to conclude is that I feel genuinely inspired by these writers and their perspectives have increased my optimism and hope for a better future.

While this thoughtbook is about the future of engineering, I like to think that a professional or student of any discipline could pick it up and feel somewhat enriched by the vignettes and reflections in it. In this working world where skills are increasingly less siloed, and industries are increasingly entangled, it is fitting that the material we read reflects this too. With that, I'll leave you. I hope you enjoy it.

Kumar R. Parakala
President, GHD Digital
Chicago, January 2020



HOW TO USE THIS THOUGHTBOOK

If on a summer's day an engineer...*

A note from the Editors

You are about to begin reading the "Tomorrow's thinking, Today's people," a thoughtbook to reimagine the future of engineering, human-anchored with digital possibilities. Relax. Concentrate. Put your phone to the side or perhaps farther away. You shouldn't ignore your phone usually. Your friends, family and colleagues are trying to talk to you. But on this occasion, it may distract you as you read. At the office, all your colleagues are trying to confirm the next meeting but you politely dismiss their gestures. You say, "I'm reading a thoughtbook on the future of engineering!" They will understand. If they don't, leave quietly and find a spot where no one is likely to bother you.

It's not that you expect something from this thoughtbook. You are the sort of person who has learned to carry less weight to expectation. You want to wait to consume something before making a judgment. But you are curious. Engineer or not, you want to know what these writers have to say. It looks like a dense book, difficult to digest but fear not, this is why we write you now, to help you through it. While we list the themes in order below, you understand that is not necessarily how to engage with the thoughtbook. You are the kind of reader who makes their own decisions. You might read from here to the end, or start midway or you might go to the last pages and start your discovery there.

To help make sense of it all, we have provided five themes. We hope this helps you pick where your deepest interest might lie, a place to begin perhaps. We begin with **"New Mindsets, New Thinking, New Tools"** and hope you might ponder the challenges of the future and your place in them. Do the words resonate? You read *Charlie Day's* piece and start to reconsider what you thought engineering meant. You read *Sylvain Emeric's* perspective and see yourself as a "philosopher in action". Does it spark your interest about the future mind of an engineer?

The next section explores a major essence of the book, **"Reengineering the Engineering Discipline"**. Does the title prompt you to consider that engineering is a dynamic profession and therefore, by nature, must evolve with time? In this section, you have a choice of anecdotes and opinions about how the engineering profession must change to meet the demands of Industry 4.0. Be it *Elanor Huntington's* exciting piece calling for engineers to restore the trust the public puts in them or *Adela McMurray's* argument for human enablers for technology, you can see there is much work to be done in redefining the engineering vocation.

Please flip through the pages and when you do you will be smack bang in the middle. That is where you find the theme **"Convergence and Collaboration"**. We know it might sound "buzzwordy" but please give it a shot. You read the first piece by *Sally-Ann Williams*. We think she has a good point: our most precious resource is no longer in the ground. Then you look at *Graeme Henderson's* piece. Does it makes you question who will take the reins to shift the engineering industry to where it needs to be? Shall we continue?

You might notice the Alice in Wonderland reference in the next chapter **"Through the Looking Glass"**. Maybe like Alice you are becoming "curiouser and curiouser"? Here many of our writers are not engineers and some work outside but in tandem with the engineering industry. Hopefully this interests you as it falls in line with the opinion in this book that the profession needs to diversify. Does the first piece by *Jacqueline Linke* catch your eye? It discusses the importance of "intrapreneurs", those who affect change from within large organisations. Please take your time and peruse through the rest of the section; maybe settle on *Michelle Mannering's* contribution, which defines and outlines the word "technology" in an uncommonly inclusive way.

You are nearing the end now. There isn't much book left but there is one last section and it's pretty important. It is called **"Future Voices"**. Do you want to know what the younger generation are thinking at this moment? These are the engineers of the future. They are the ones who will benefit most from this thoughtbook. They contribute with hope and optimism about what the future will bring, and what is sincerely possible.

So here you are now. Please head into the thoughtbook as you wish. Immerse yourself and enjoy. From our end, it has been a pleasure to work with these writers. They are keen to begin a conversation with you, dear reader, and we hope you feel likewise inclined.

*** Editors' Note:**
We would like to acknowledge the late Italian writer Italo Calvino for inspiring the style of this note with his book *If on a winter's night a traveler.* We highly recommend you read it.

THEME 01

NEW MINDSETS, NEW THINKING, NEW TOOLS

THEME 02

REENGINEERING THE ENGINEERING DISCIPLINE

THEME 03

CONVERGENCE AND COLLABORATION

THEME 04

THROUGH THE LOOKING GLASS

THEME 05

FUTURE VOICES

New Mindsets, New Thinking, **New Tools**

How might we prepare, equip and empower our future engineers for tomorrow's challenges?

CHARLES DAY

INNOVATOR/ ENTREPRENEUR/ BOUNDARY SPANNER BETWEEN GOVERNMENT, BUSINESS AND ACADEMIA

> "WE SHOULDN'T NEED A SPECIAL WORD CONNECTING IMAGINATION AND ENGINEERING, BECAUSE IMAGINATION IS THE VERY ESSENCE OF ENGINEERING."

The *ephemeral-isation* of **engineering**

Charles Day

A popular (mis-)conception of engineers is that they work in the realms of the tangible—making bridges, cars, factories and the like, necessitating that de facto uniform of a hard hat and steel capped boots that so often appears in the mass media. Anyone who has been close to the profession in recent years, though, knows that it's an outdated stereotype—that engineers work in a myriad of settings, and use some of the most powerful digital tools to work in parallel "virtual" worlds even as they seek to manipulate the atoms of the physical world. And any examination of the material and digital worlds we inhabit today would have to acknowledge the enormous debt we owe to contemporary engineers.

But even so, I'm not convinced that we have fully come to terms with the extent to which Industry 4.0 is changing the profession. It will, in the words of World Economic Forum (WEF) Chairman Klaus Schwab, "fundamentally alter the way we live, work, and relate to one another", but more than that it will alter the types of challenges engineers have to face. It will extend the process in advanced economies of dematerialisation—or as architect Richard Buckminster Fuller more memorably put it, "ephemeralisation"—which is the notion that we can satisfy human desires for consumption whilst using fewer resources from the physical world. But at the same time as we place fewer demands on physical resources, we will place greater demands on less tangible resources such as information and knowledge.

Indeed, as Jonathan Haskel and Stian Westlake argue in their book *Capitalism without Capital: The Rise of the Intangible Economy*, it is increasingly intangible assets, rather than tangible assets, that are driving modern economies. As they note, intangible assets have very different characteristics to their tangible cousins. The tangible assets I learned about as a budding engineer tend to generate value in predictable ways and lose value over time in a steady process we call depreciation. Intangible assets, on the other hand, are highly scalable, feature significant sunk costs, generate spillovers well beyond their creators, and offer the potential for significant synergies. If the role of engineers is to solve problems and create value for society, these very different characteristics will take some getting used to. The rules of thumb we have used to navigate (and engineer) a predominantly tangible world will serve us poorly in a world dominated by intangible assets.

What does this mean for engineers and the engineering profession? I see three key components to consider.

Firstly, we will need to continuously rethink what engineering means, inventing new disciplines along the way such as that being built by Elanor Huntington, Genevieve Bell and colleagues at the ANU's 3A Institute. This institute is bringing a truly interdisciplinary approach to framing the responsible use of artificial intelligence (AI). It's ensuring that we retain the centrality of humans in an increasingly technological world, and it's a vital part of the path forward. But we will also need more evolution in the profession—better approaches to engineering economics that more effectively handle the intangible assets mentioned above, for example, as well as better integration between engineering and other disciplines, including in particular the humanities.

Secondly, we will need new firms and new ways of working that can bring the best of our centuries of experience with engineering our physical worlds and combine it with the new possibilities of the virtual world. Such firms will still be called upon to solve the most knotty challenges, and optimise the most complex systems, but they will do so in a multidimensional solution space, where processes are bespoke and outcomes are hybrid. Finding the best organisational form to deliver such outcomes will be an ongoing challenge.

Finally, we will need to have a profession and an engineering education system that fully leverages that most human of traits: imagination. This has always been embedded in the name of our discipline, derived as it is from the same linguistic root as the term "ingenuity", but in our recent focus on technology I fear we may have lost some of its essence. Indeed, I remember being a little deflated when I learned that the Walt Disney Corporation had appropriated the term "Imagineer" to describe the people who design the experiences at their theme parks. Don't get me wrong—they do amazing work, and have probably created more joy for more children than many of us can hope to lay claim to in a lifetime. But for me the notion of imagination and creativity which "Imagineer" evokes has always been, and should always be, a core feature of the discipline we call engineering. We shouldn't need a special word connecting imagination and engineering, because imagination is the very essence of engineering. And if we are to successfully navigate our virtual future, we need to rediscover it and fully embrace it.

Industry 4.0 is a prospect that I find both daunting and energising at the same time: a chance to simultaneously address the flaws of our current systems whilst also creating entirely new ones of previously unimaginable capability. If we are to generate the true prosperity dividend that seems to be on offer, engineers will need to skilfully adapt their profession to the increasingly virtual world humanity is creating.

Unlocking the engineer's **creative potential** through constraints

Rachel Audigé

Engineers often tell me that they are not creative. I do not believe this is true and I would like to dispel that notion. What I do believe, however, is that engineers have a major blind spot when it comes to innovating and this can impact both their ability to come up with more inventive and resourceful ideas and their capacity to "stress test" ideas and concepts once the wheels are in motion. These are skills that will be paramount for the future of engineering and Industry 4.0.

So, what is this "major blind spot"?

Engineers are conditioned by the positivist paradigm whereby knowledge is objectively true or false and as perfectly observable (like gravity and voltage). For many of the things engineers do, this is a helpful mindset. A bridge really does either hold … or collapse. However, the positivist universe actually leaves no place for bias, because it leaves no place for interpretation. "If the positivist universe has a bias, it is the belief that bias has no influence", explains my friend, Streicher Louw, a profoundly inventive engineer and Head of Behavioural Strategy at nbn™ Australia.

And yet, cognitive bias permeates our thinking on every level. Melbourne based thought leader Steve Glaveski tells us "there are over 100 biases impacting our perceptions and beliefs at any one time and 36 of them have an immediate impact on our ability to innovate."

One bias that has enormous impact on innovation is **"cognitive fixedness"**. Cognitive fixedness is a state of mind in which it is easy and natural to perceive aspects of the world in a particular way and very difficult to see them any other way. It may take one of three forms:

- **Structural:** where a system is locked into a certain configuration (as GE did with the fridge for decades!).
- **Functional:** where we cannot imagine an alternate function for a component (e.g. a piece of medical equipment is designed with spare batteries and a screen when it could simply have been connected with a monitor in the operating theatre with both).
- **Relational:** where we lock in dependencies between two variables and can't imagine alternatives (pre "Happy Hour", for example).

So how can engineers overcome bias when coming up with ideas?

There are three very powerful skills that should be honed:

- **Engineers need to learn to work better with constraints.** They need to impose constraints on the problem solving process, product or system and then work more systematically with the resources they already have. Listing the inventory of resources available is a simple way of avoiding blind spots. Following a path of most resistance and avoiding adding new resources is a more realistic way to innovate in a resource-constrained world.
- **Engineers need thinking tools that help them use existing resources in novel ways.** Once constrained, they need ways of thinking differently about the resources they have. This is where it is helpful to harness thinking tools that are derived from great ideas. Innovation methods such as Theory of Inventive Problem Solving (TRIZ) or Systematic Inventive Thinking (SIT) offer this. These are methods that were founded on the observation of creative patterns in the best ideas. These patterns have been reverse-engineered into thinking tools that give you a greater chance of coming up with something innovative.

RACHEL AUDIGÉ

COACH/FACILITATOR/ RESEARCHER/ 'INSIDE THE BOX' THINKER

> "THIS "INVENTIVE STRESS TESTING" NEEDS TO BECOME THE NORM JUST LIKE THE SYSTEMATIC DUE DILIGENCE WE HAVE AROUND SAFETY AND QUALITY ASSURANCE."

- **Engineers need more agility in their thinking so that they can come up with forms and ask what they are good for.** Given how embedded this bias is in our thinking, we need ways of "suspending" it. Engineers have mastered the art of thinking from a problem to a solution. This is the standard waterfall approach. What they need to learn is to do the reverse: break away from waterfall thinking to think "form to function" or "solution to problem," so that they cannot embed default or biased thinking into the ideas at the outset. Both of these are the sweet spot of SIT.

And how does this relate to "stress testing" ideas once the wheels are in motion?

Picture this: in the 1970s, the United States and the Soviet Union were competing in the quest to explore the moon. Some of the smartest engineers in the world were put on the project. Unable to send up a manned ship, the Soviet Union decided to launch an unmanned lunar probe to take an autonomous vehicle over to the dark side. The light source was the incandescent light bulb. The problem was that they would not survive the impact of landing on the lunar surface; the light bulbs kept breaking!

Even the toughest bulbs cracked during tests. A major effort was started to figure out how to strengthen the glass bulb. The situation was reported to the director of the Moon Landing project who queried the role of the light bulb. Clearly the bulb served to seal a vacuum around the filament. However, given that this was an oxygen-free environment, this wasn't required.[1]

The solution was simple: remove what they had thought was an essential component: the bulb. The filament burnt happily in space without the bulb and the team were left looking at each other wondering "Why on earth didn't I think of that"?!

No amount of systems engineering or project management would have flagged this as a solution. Indeed, a systems engineer project plan would have embedded the assumption from the outset! However, had they designed the lunar probe scanning for different types of fixedness from the start, the time, resources and expense of solving the problem could have been spared.

Engineering projects should involve regular assumption challenging and bias-scanning sessions. This "inventive stress testing" needs to become the norm just like the systematic due diligence we have around safety and quality assurance. Most projects cannot afford to leave better ideas off the table—or to realise them when it is too late in the schedule to implement them.

Being able to recognise cognitive fixedness, bust it and scan for it throughout any engineering project are skills that our engineers need to understand and hone if they are to be powerful innovators in a complex, resource-constrained world.

[1] "Innovation on Demand", V. Fey, E. Rivin, Cambridge University Press, 2005, p. 5.

Engineers: the "philosophers in *action*"

Sylvain Emeric

SYLVAIN EMERIC

MANAGEMENT CONSULTANT WITH FOCUS ON DESIGN-LED INNOVATION AND DIGITAL TRANSFORMATION/ FORMER MECHANICAL ENGINEER/ ASKER OF "CATALYTIC QUESTIONS"

In the spring of 2004, I remember touring French cities with my mum to attend several engineering "Grandes écoles" fairs. This was my last year of high school which comes with *the* important question to answer: "Who do I want to be when I grow up"?

Fast-forward five years later and I was graduating from INSA Lyon with a Master in Mechanical Engineering and Design. Beyond its reputation, the reason I chose this particular school was twofold: an exposure to other cultures through one of their international programs that saw students from different countries study together, and a very unique perspective on what it means to be an engineer as a "philosopher in action." I saw it as a vocation that not only produces technological solutions but also considers deeply their application and impact on society.

I've always had a strong interest in science, and engineering seemed to be the perfect way to apply science to complex problems faced by society. Off the back of my engineering degree, I completed my first engineering internship where I worked on aircraft lateral trajectories compliant to new aeronautical standards for six months. While it was fascinating and enhanced my technical skills, I realised that I didn't want to work on just one element of a puzzle for months or years. Thus, I went on to complete a Master in Business, which enabled me to develop the big picture lens I desired. Management consulting emerged as a career where I would be able to combine my interests for business and technology.

> "JUST LIKE A PHILOSOPHER, THEY WILL ESSENTIALLY NEED TO MASTER THE ART OF QUESTIONING, NOT JUST ANSWERING."

In the first two years of my career, I felt a little bit out of place in the consulting industry. The type of problems I was solving seemed ill-defined and not concrete and I was spending a lot of time trying to understand and manage people's expectations. Therefore, I didn't feel like I was using my skillset effectively. As a management consultant, the main objective is to help organisations perform better. As such, we introduce new changes to improve our clients' organisations. While the nature of the change can take many shapes and forms such as a new technology, a new process or a new product, the recipients of the change, the ones that will need to adopt it, are invariably *people*. However people are a lot less dependable and predictable than a technical solution. Humans all have different needs and wants, they value different things, and these can evolve with time. From spending many years building deep technical foundations based on scientific knowledge and applying logic to solve problems, I now had to be a lot more nuanced and take into consideration humans' needs and wants into the design of solutions.

What I've learnt in my career as a consultant is that it is fundamental to put the people at the centre of the change that we're intending to drive or the solutions we want them to use. If we can't articulate how the change or the solution will alleviate peoples' fear, or provide them with something that they value, then no matter how ingenious the solution is, it will most likely fail.

If we look at industries that have typically required engineering expertise such as aerospace, environment, water, energy, buildings or transportation, while extremely technical and complex, these industries are also at their core, human systems. They greatly affect citizens on a daily basis, whether it be directly or indirectly. As we enter this new decade in the digital age, people are more empowered than ever before. This means that they are better informed and acutely aware of all their options, or lack thereof. Comparisons they are now making are not limited to the scope of a particular company or industry. If we look at transport as an example, certainly, people will compare their Uber to their taxi experience. Similarly, they are likely to also compare their Uber experience to their train experience. How can a train ride feel more like an Uber ride? And how can each mode of transport talk to each other to provide an integrated and seamless transport experience for commuters? These new problems will require a lot of technical problem solving, but most importantly, they will need a great deal of empathy and building solutions that are human-centered. With that in mind, it is no surprise that a vast majority of companies operating in these industries have identified customer and community centricity as a strategic imperative to deliver against.

So what are the opportunities for engineers and the future of the profession?

I started this story with the vision of an engineer as a "philosopher in action" and the sense of societal responsibility they have by thinking about the impact of the technologies introduced to the world. I believe this holds some of the answers for how the profession needs to continue evolving.

As we embark on this new decade, technological revolutions will continue at unprecedented pace and scale. These will fundamentally challenge the way we live, the way we work, how organisations operate, collaborate and do business, or how we tackle some of the greatest problems faced by our societies.

In that context, questions engineers will be required to answer will evolve from "how to build things?" to "what things to build in the first place and why?" They will need to spend more time on problem identification and understanding, from the perspective of the people experiencing the problems, rather than just solving for the technical components of the problems. Just like a philosopher, they will essentially need to master the art of questioning, not just answering.

To achieve that, future engineers will need to demonstrate T-shaped skills: the vertical bar representing the depth of technical knowledge acquired in their discipline and the horizontal bar representing the breadth of knowledge acquired through empathy, curiosity and collaboration with other disciplines.

By understanding and integrating people's perspective through empathy, asking catalytic questions to better frame problems before jumping to solutions, and by leveraging a broader repertoire of knowledge beyond their own technical discipline, engineers will unleash their creative potential to design and build innovative solutions that are not only technically sound, but also centered on humans' needs. They will become the "philosophers in action" society desperately needs to lead the change required for a desirable and sustainable future.

Intrapreneurship in engineering to drive **impact** at **scale**

Janett Egber

JANETT EGBER

MULTILINGUAL GLOBAL CATALYST/ ADVOCATE FOR INTRAPRENEURSHIP/ FACILITATOR/ WRITER

“I GET PARTICULARLY EXCITED WITH THE FUTURE WE CAN SHAPE WHEN ENGINEERING SKILLS AND CAPABILITIES ARE OVERLAYED WITH A SOCIAL INTRAPRENEURIAL MINDSET.”

In today’s world, engineers have the potential to drive significant impact through their work—particularly as they leverage their skills and capabilities whilst embracing new ways of thinking, new ways of working and new ways of collaborating.

Whilst we often read about inspiring stories of social entrepreneurs, we seldom celebrate and hear about the impact and contribution of “INTRApreneurs”. What is “intrapreneurship”? And specifically, “social Intrapreneurship”? Social intrapreneurship is defined as:

“An autonomous process through which individuals or groups of individuals seek to identify and exploit entrepreneurial opportunities that address societal challenges from within established organisations”.[1]

I have a very strong connection to this topic, as I’m a practising intrapreneur myself. In fact, I have been one for many years, before I even realised it. Over time I’ve learnt that this is a very common feeling. I had no idea there was a name, a language and a growing global community called The League of Intrapreneurs (LOI). This is a global learning community of intrapreneurs and catalysts working to unlock the human innovation potential inside our most influential institutions.[2] In other words, we are a community of people that have a different way of looking at business problems, have an entrepreneurial mindset and yet, work from within organisations. Why? Because we are drawn by the opportunity to drive impact at scale. I spent the past 20 years in corporate Australia and at least, the most recent five years as a practising intrapreneur in the finance sector and now as a Global Catalyst for the LOI.

As I started to connect with this community, I realised how similar the challenges and experiences were regardless of the organisation, sector or country we work from. I have often noticed how intrapreneurs are not afraid to question power structures, challenge the status quo and ask the hard questions. We don’t just ask WHY … But rather, WHAT IF?

What is the sweet spot for intrapreneurship?

Organisations need to adapt, evolve and transition in order to remain viable and relevant. We constantly hear of “transformation” projects and the need to change and innovate. But organisations don’t change … It is the people within these organisations that need to lead the change.

Throughout my experience, I’ve noticed that intrapreneurs are leading change and innovation in organisations, with a real “sweet spot” at the intersection of the following three areas:

/ Talent and 21st century leadership—people today look up to visionary and purpose led leaders. Top talent is searching for meaning beyond financial rewards as well as avenues to make a significant difference.

/ Innovation and entrepreneurship—this refers to the mindset of social intrapreneurs shared in the definition as well as an outlook of possibility and opportunity that is very characteristic of intrapreneurs.

/ Systems change and sustainability—“social intrapreneurs are pursuing what some might call the holy grail of sustainability: alignment between societal needs and business value. They see the potential for corporations not only to minimise harm, but also to create new forms of value by helping meet societal challenges.”[3]

Sometimes we are considered rebels and in all honesty, it does feel fairly isolating at times. There is no play-book, we learn as we go. We experiment, we fail, we un-learn and we share our learnings through this community.

Why does intrapreneurship present such an opportunity for Industry 4.0 and more specifically, the future of engineering?

“Intrapreneurs (like entrepreneurs) are generative thinkers. Instead of becoming trapped by the “tyranny of the OR” intrapreneurs are able to see over the horizon to new possibilities. They can reconcile seemingly irreconcilable views—like green and profitable or mass market and high quality. Roger Martin refers to this capacity as the “opposable mind”.[4]

I get particularly excited with the future we can shape when engineering skills and capabilities are overlayed with a social intrapreneurial mindset. I do believe that the opportunities can be game changing for those that look to embrace this new way of thinking and nurture an environment for social intrapreneurship to thrive.

“Generative thinking is one of the greatest gifts that intrapreneurs bring to problem solving. They see problems in a wider context of “system” and identify patterns and interconnections that can help unlock solutions where progress has stalled”.[5]

Industry 4.0 and the future of engineering has the potential to address some of the systemic issues we face as new mindsets are applied not just for problem solving but most importantly for system thinking and collaboration.

I’ve been incredibly fortunate to meet many intrapreneurs from around the world, all true collaborators and system thinkers. Whilst much has been written about collaboration to drive social innovation and impact, many of the intrapreneurs in our community acknowledge that collaborations with external partners still fall short. According to Asa Skogstrong Feldt at IKEA, “Most partnerships involve working side by side, rather than true collaborations. And yet, innovation research underscores the importance of collaboration—from the combining of new and unlikely perspectives; sharing risk and opportunities to leveraging diverse strengths. And the UN SDG number 17 is urging collaboration for systemic change”.[6]

I’m a firm believer that intrapreneurs are shaping the future. This is an open invitation for you to integrate an intrapreneurial approach and generative thinking towards the future of engineering—so, we can work on the problems that are worth solving and drive real impact at scale, together!

American writer Margaret Wheatley could not have articulated it better when she said “The world doesn’t change one person at a time. It changes as networks of relationships form among people who discover they share a common cause and vision of what’s possible. This is good news for those of us intent on changing the world and creating a positive future. Rather than worry about critical mass, our work is to foster critical connections”.

1 Intrapreneur’s Guide to Pathfinding, p. 12 // see reference no. 9 – p. 195.
2 www.leagueofintrapreneurs.com.
3 The Intrapreneurship Ecosystem white paper, p. 15.
4 The Intrapreneurship Ecosystem white paper, p. 16.
5 Intrapreneur’s Guide to Pathfinding.
6 The Intrapreneurship Ecosystem white paper, p. 38.

The *evolving engineer* is the **best engineer**

Richard Bolt

RICHARD BOLT

STRATEGIST/ ADVISER/ LEADER/ CHANGE AGENT/ THOUGHT LEADER FOCUSED ON THE POTENTIAL OF HYDROGEN FOR ENVIRONMENTAL AND REGIONAL PROSPERITY

> “A PROFESSIONAL CULTURE BASED ON SCIENTIFIC LOGIC MAKES IT HARDER FOR ENGINEERS TO SEE THAT THEIR VIEWS ARE INFLUENCED BY VALUES WHICH ARE NOT INTRINSICALLY RIGHT AND MAY NOT BE SHARED BY OTHERS.”

35 years ago, politics and policy attracted me and I decided to leave my engineering career, a decision which was reinforced by my discomfort with attitudes and practices in the profession.

This concern was epitomised by my organisation’s handling of a black ban on a new computer-based control system, which had been designed by my department to be operated by another department. The operators were demanding changes because our solution tied them to their chairs over long shifts to look at small screens. And none of the screens could show them the entire power network for which they were responsible.

They had a simple demand: a wallboard that would allow them to move around the control room while always having a helicopter view of the network. They would use the screens to remotely operate equipment or diagnose a problem.

My department was comprised mainly of engineers. They reacted defensively so the ban was imposed. One day (month three of my career), I was sent to the control centre to mind the fort while negotiations continued at head office. The lead operator took the opportunity to explain his concerns to me. I saw his point, and expressed that support to the control centre manager when he sought my view.

This honest statement set off a remarkable chain of events. My view was relayed up to the head of the operations department, by him to the head of my department, then down to my boss. The next day I was dressed down for offering an opinion on a subject I knew nothing about. But three weeks later when heads had cooled, the wallboard was agreed and the ban was lifted. This episode illustrated why technology should be designed to serve its users’ reasonable needs, which should be identified through early dialogue with them. While the wallboard cost money, it reduced risk. Every network control centre I’ve seen has one.

Unfortunately, I didn’t fully grasp the lessons of that episode. Years later I was running energy policy for the Victorian government. Having successfully proposed a roll-out of remotely read digital meters, I didn’t anticipate older peoples’ reaction. Some felt the change was being imposed and would put their health at risk from the radio waves that would transmit data back to base. The business case for the rollout was strong—better customer service, more reliable networks, improved electrical safety, better usage information for customers—but we were caught off guard by this opposition. The rollout was put at serious risk, though it ultimately proceeded.

These anecdotes contain lessons for the future of engineering. Momentous digitalisation changes are happening through the Internet of Things (IoT), data analytics, robotics and automation. An energy transformation is happening in parallel, driven by climate change and the economic risks of rapid fossil fuel extraction. Our cars and many appliances will be electrified, fossil fuel power will give way to renewables, and hydrogen production will grow to firm the grid and tackle the hardest decarbonisation tasks. How we work, move, live and even eat will change.

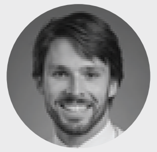
This technology transformation has a central role for engineering, and a serious challenge. Handled well, it will improve our public services, private amenities and economic productivity. The challenge is to do this in close partnership with the public. Careful dialogue will help engineers adapt technology to society’s values, preferences and capacity to adjust.

The core skill of engineers—designing, building and maintaining structures and systems—will remain critical. But it will also be critical to understand what society wants and what it fears. A community which foresees an avalanche of change will reject those elements they don’t like or understand. Politicians fearing a volatile electorate will support voters who believe their jobs, budgets or amenity are at risk. This challenge is not entirely new, and engineers have become increasingly aware of their social and environmental responsibilities. What’s genuinely new is the size and stakes of the challenge. Energy transformation will tackle a global threat by catalysing change in households and businesses. Digitalisation can raise productivity and living standards but may put millions of jobs in doubt.

The result is that many future technology changes will be contested. Who could argue against camera-controlled intersections which use artificial intelligence to improve traffic flows? Answer: people who fear their privacy will be breached. Who could argue against growing the use of clean hydrogen to lower carbon emissions? Answer: people who fear their homes may go the way of the Hindenburg airship.

Engineers find social opposition particularly challenging when it appears to lack an objective reason, such as the ban on hydraulic fracturing (“fracking”) to extract onshore gas, or the rejection of modern nuclear reactors. This may be because engineers are trained in applied sciences in which facts dominate and risks are quantified. Understanding optimisation may make it harder to also understand how people can accept the binary choices and politics that dominate popular debate. A professional culture based on scientific logic makes it harder for engineers to see that their views are influenced by values which are not intrinsically right and may not be shared by others. For example, the public may remain wary of nuclear power because they don’t like risks that have very low probabilities but disastrous consequences, whereas the values embedded in engineering practice may support that option because the probability-weighted cost of failure is low.

Rather than lamenting popular attitudes, engineers are better served by learning to engage with them. The social sciences provide useful explanations for the contrasting behaviour of the public, politicians and professionals. Engineers will have more impact by integrating these insights with their technical knowledge. They should learn how to gain social licence by teaming with other professionals to forge respectful partnerships with the various communities of interest. There is a large and essential role for engineering to improve our lives and tackle the great public challenges of the 21st century. The profession will need to keep changing to makes its best contribution.



MYLES COKER

DESIGN THINKING AND PRACTISING "ENVIRO"/ SURFER/ INNOVATOR/ RESEARCHER/ FACILITATOR WITH A PASSION FOR SUSTAINABLE WATER PRACTICES

How *surfing* can put **human-centred engineers** to the test

Myles Coker

> "TODAY, GREATER VALUE IS OFTEN CREATED BY THOSE WHO MAINTAIN A SHARPER FOCUS ON THE EXPECTATIONS, NEEDS AND WANTS OF USERS, CUSTOMERS AND THE COMMUNITY."

At the 2019 World Engineers Convention held in Melbourne, something stood out to me. It wasn't so much the incredible technical knowledge being showcased, although that was in abundance. What struck me was how global circumstance and our own desire to contribute more to society is challenging the very nature of the engineering profession.

Engineering today remains a critical contribution to society, particularly as we set out to achieve each of the sustainable development goals. It is clear, however, that *how* we make that contribution is rapidly changing. To adapt, we are reconsidering how we tell our story, share knowledge, acquire skills, work together, lead people, use data and adopt technology. The recent meeting of engineers enabled us to explore each of these critical shifts at a global scale.

While engineers could be forgiven for being uncomfortable with the need for change, I am inspired by how established and emerging leaders are leaning in to shape the future of engineering. Even in my short career, I have sensed a subtle shift in the openness within engineering to do things differently.

I graduated ten years ago as an environmental engineer. At that time, "Enviros" weren't always considered "real" engineers by some of the longer standing engineering disciplines. Fortunately we took it as a compliment. We banded together and fostered a strong sense of belonging among ourselves. As my career evolves, I maintain my close bond with the Enviros and many "real" engineers, while working more and more with human-centred designers and creatives to solve complex problems for service providers.

Despite popular belief, engineers are not only technical but also empathic and have the interpersonal skills required to discover insights and design for what people value. However, many of us were conditioned as engineering students to think first and foremost about the technical feasibility of a solution rather than its desirability or social sustainability. Today, greater value is often created by those who maintain a sharper focus on the expectations, needs and wants of users, customers and the community. Let's say this focus is a trait of more "human-centred" engineers.

To highlight the technical bias in "real" engineers I have come up with a simple test inspired by the "push test" in surfing. In surfing, most people prefer to stand facing to their right with their left leg forward. It's termed the "natural" stance. Think of these people as the "real" engineers focused on technical solutions. The minority of surfers, like me, stand with their right foot forward. It's termed the "goofy" stance, likely a nickname coined by "natural" footers. Think of these "goofy" people as "human-centred" engineers. To test whether you surf "natural" or "goofy", stand with your feet shoulder-width apart and get a friend to shove you in the back. Whichever foot you instinctively place in front to stop yourself from falling, is likely your preferred front foot on the surfboard. You can do a similar test to identify whether you are a "real" engineer. Get someone to pitch a new, crazy idea to you. If your first instinct is to think of reasons why it won't work, then you are more traditionally conditioned. If you first think of reasons why it may not meet the expectations, needs or wants of people and community, then you are one of an emerging breed of human-centred engineers.

To solve the complex problems facing society today and in the future, we need a diversity of thought and that includes all types of engineers. You can even place yourself "on the engineering spectrum" if you feel human centricity is not binary. So, would the real engineers please stand up? I recommend a human-centred stance. It may feel a little goofy to start with but there is a whole lot of value for engineers and society in sticking with it.

Engineers' *evolving* responsibility to their **communities**

Alexe Bojovschi

ALEXE BOJOVSCHI

TECHNOLOGY INVENTOR/ BUSINESS INNOVATOR/ RESEARCHER/ TEACHER/ AUTHOR

I would readily forgive anyone who finds it overwhelming to sit down and reflect sincerely on the point in history that we are currently living in. The problem is that as soon as you reflect, a series of new things have already appeared and now you have to revaluate again. That said, it is always a noble attempt. As an engineer, I spend much time thinking about the past, present and future of my profession. The expansive array of engineering advances, challenges and opportunities are poised to reshape the future of our societies and environments. Our approach to technology is indisputably decisive in moulding the future that we envisage for ourselves. To that end, careful interaction and tuning of technologies becomes possible and complex due to multiple parameters that come into the equation of product development. Some aspects of how we design effective engineering solutions need to adjust as per the time we are living in. We need to approach other disciplines with interest and learn from them. While we do work in an environment where we have a clear responsibility to deliver a solution to stakeholders, we also must consider how we can use our solutions to help our communities.

Social networks and human interaction in technological development becomes more important in connected systems. They have the potential to facilitate optimisation of globally deployed technologies that are not only competing but also work together for the future benefit of the community and the planet. Some of the technological advances that connected and enabled global communities include the internet, satellite networks and transportation systems. They have also opened the path to global digital and business innovations that accelerate attention to engineering challenges for immediate benefits for human beings and the planet.

It is likely that the evolution of engineering will go beyond historical trends of segmented technologies that, in a valuable way, address problems and develop useful solutions. The need of diverse technologies integration and tight correlation with social networks has the potential to optimise aspects such as engagement, energy usage and environmental impact. In this example, artificial intelligence (AI) will guide multiple decisions to develop for example smarter materials, sensors and urban and extra-terrestrial environments.

Some of the current engineering challenges include addressing energy consumption, pollution, health, a disconnection to nature and accelerated urbanisation. They require systems thinking not only to improve human experience, their connectedness to both nature and technology but also to optimise globally both the resource usage on the planet and the technological impact on the environment.

One of the current health-related challenges is the development and use of nanoparticles that can immediately have a clear benefit. However, the long-term effect is not well known. Studies indicate that apoptosis, aka the death of cells, can be triggered by specific doses of nanoparticles. Although this information is useful, the real cause of cell death is in most cases is unknown. To answer that question, understanding at molecular level the interaction between nanoparticles and cell membranes, proteins, enzymes and other molecular systems is required.[1] These are very challenging and in some cases still impossible with current supercomputing or grid computing resources.

Another challenge is developing and reconfiguring power networks to optimise the usage and distribution of energy from an increasing number of systems such as solar, wind turbines and hydro power plants. The use of augmented intelligence provided by distributed sensors networks working in tandem with AI have the potential to optimise energy generation and usage. Also, the power network reliability and security that is critical in an interconnected society requires monitoring the health profile of power components using sensors and employing AI to predict future states of the power network to prevent imminent failures.[2]

AI was shown to be beneficial for the discovery of smart materials in relevant or emerging industries.[3] For example, Carbon Fibre Reinforced Polymer (CFRP), which was developed using an atomic level understanding and data science, has now been adopted in multiple industries as a structural material. It was also proven to be suitable for radar systems as a load bearing antenna. The use of CFRP not only significantly reduces the weight of vehicles and aeronautic systems and consequently contributes to reducing energy usage. The engineering of current and future technology will rely on this search for intelligent solutions relying on chemistry, AI, physics, engineering, social needs and environmental benefits. Although integrating the knowledge from all these verticals to devise optimum decisions was challenging before, now the use of current computer resources and AI can facilitate this process.

> "RECONNECTING THE FUTURE ENGINEERS TO NATURE IS A KEY ASPECT THAT CAN ENABLE THEM TO APPRECIATE NATURE IN THE SAME WAY THEY APPRECIATE TECHNOLOGIES."

Past engineering revolutions led to outstanding technological benefits and human life convenience and experiences. However, some current challenges are emerging that are sometimes triggered by the disconnection to nature. This results from multiple factors and urbanisation is a dominant cause. Reconnecting the future engineers to nature is a key aspect that can enable them to appreciate nature in the same way they appreciate technologies. Humans are most connected and appreciate the things they learn about, touch, experience and build. One of the current efforts to connect the next generation with nature is the vertical garden development by high schools across Victoria. The connection to the environment is important because the best innovation role model is nature. It can have at least dual benefits, one is nature-inspired technologies and another is understanding how technologies can be developed to support the environment instead of working against it.

[1] A. Bojovschi, Ming S. Liu and Richard J. Sadus, "Conformational dynamics of ATP/ Mg:ATP in motor proteins via data mining and molecular simulation", The Journal of Chemical Physics, 137, 075101, 2012.

[2] A. Bojovschi, "Electric fish inspire technology to detect faults in power networks", ABC Science Show, Link: https://www.abc.net.au/radionational/programs/scienceshow/electric-fish-inspire-technology-to-detect-faults-in-power-netw/4908368.

[3] Tu C Le, David A Winkler, "Discovery and optimization of materials using evolutionary approaches", American Chemical Society, 116, 6107-6132, 2016.

MIKEL ALONSO

CITY SHAPING RESEARCHER AND PRACTISING ENGINEER/ MULTIDISCIPLINARY LEADER AND ADVOCATE FOR MULTIMODAL AND INNOVATIVE SUSTAINABLE TRANSPORT SOLUTIONS

Times are a *changin'* for **aspiring** infrastructure professionals

Mikel Alonso

When I attended university in the late 90s, our academic years were carefully structured and broken down into stand-alone subjects. I once took a great subject called Engineering Design, which was meant to help students connect the dots of skills learned in other subjects and equip them for the future. Unfortunately that professor approached it as a stand-alone academic subject. He would get lost in the "art of design" per se, without bringing real creative thinking into the fold. There was no avenue for us to bring a different lens to our work. We would learn to do things in a specific way very well, with little room for error or experimentation. It was tunnel vision! Interestingly, I found only group project work would sometimes spark students to connect the dots. As the years have gone by in this time of rapid technological and societal change, these courses have significantly evolved in depth and complexity.

> "AS WELL AS TECHNICAL SKILLS, INFRASTRUCTURE PROFESSIONALS NEED TO FOCUS ON DEVELOPING SKILLS LIKE COMMUNICATION AND STORYTELLING, CO-CREATION AND DESIGN THINKING."

As students, we were guided and taught by academically minded professionals, which proved most helpful early in my career. However, the hindsight of time has made me realise that the bigger picture and inter-disciplinary "empathy" was not a priority, consciously or otherwise. And this was for a course with a strong "systems" component. When I graduated, I was well prepared for my PhD. And when I finished my PhD I smoothly transitioned into engineering consulting, where I also analysed, calculated and designed aspects of "stand-alone" projects. I started in a division that prided itself on being a centre of excellence for the modelling and design of complex systems in transport projects. Each business stream would typically sit in their own partitions, with rare inter let alone trans-disciplinary co-creation. Professionals would evolve to master their area of practice with admirable depth in technical excellence. This was and still is the paradigm of many professionals. And for sure, developing a practice along those lines was and probably still is valuable for small to medium simple projects.

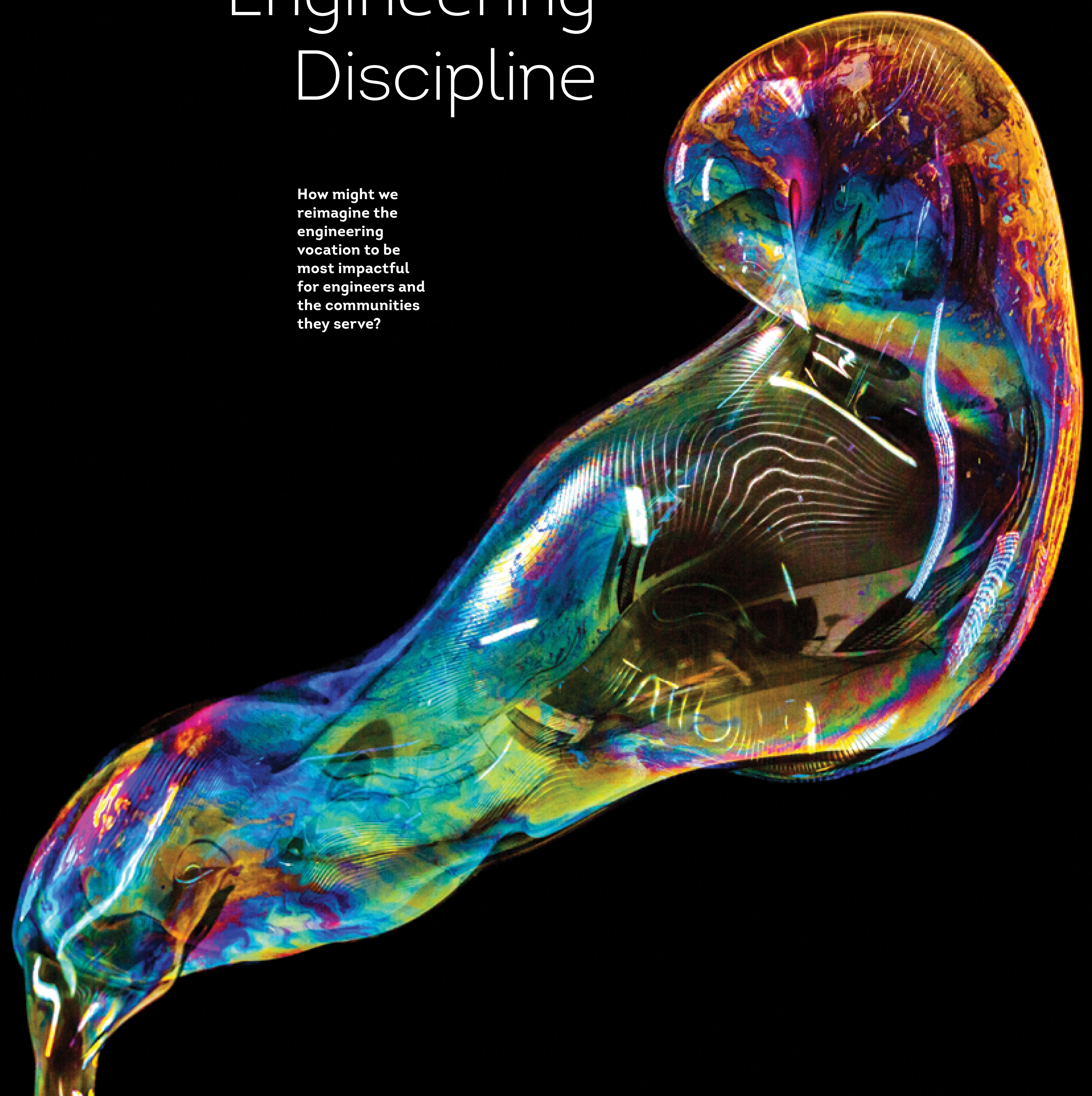
These days however, the challenges our cities and regions face increasingly fall under the "wicked problem" umbrella, and new sets of skills, attributes and experiences are required to keep abreast with change. Unfortunately, our secondary and tertiary education is lagging behind in this regard—albeit many universities recognise it and are reacting to it in some countries. Most people recognise that infrastructure professionals are confronted with varied layers of complexity that include multi-faceted challenges like profit-less booms, digital disruption, aging infrastructure, growing transport demand, increasingly complex and large projects, inadequate project risk allocation, work-force resilience, lack of real diversity and inclusion, and the list goes on.

Our future professionals not only have to develop a minimum critical mass of conventional skills and become chartered or qualified in their area of practice but they need to do this in conjunction with developing new technical skills including those necessary to leverage digital practices like automation and inter-disciplinary digital design. This includes learning enough to make sure our future tunnels, bridges, buildings, dams and highways continue to be safe, efficient and effective. In most cases, I believe the initial formative years, where you are building a diverse repertoire of key skills, is still vital to become a professional in your field of practice.

However, as well as technical skills, infrastructure professionals need to focus on developing skills like communication and storytelling, co-creation and design thinking, to name just a few. This is far easier said than done. We also need greater focus on skills like adaptation, resilience, collaboration, creativity and entrepreneurship. I often recommend to my younger colleagues, mentees and peers to continuously strengthen their area of practice while looking out for a range of mentors and project experiences that can guide them and facilitate the broadening and deepening of soft skills, attributes and experiences in their current career stage. It is the ability to consciously and purposefully bring it all together that will enable you with the tools, habits and practices to succeed.

Reengineering the Engineering Discipline

How might we reimagine the engineering vocation to be most impactful for engineers and the communities they serve?



Engineering is about technical trust at **scale**

Elanor Huntington

ELANOR HUNTINGTON

AWARD-WINNING FIRST FEMALE ENGINEERING DEAN OF ANU/ MYTH BUSTING, DOC MARTIN WEARING RESEARCHER AND LEADER REIMAGINING SCIENCE AND TECHNOLOGY FOR THE FUTURE

> “
> WHAT HAPPENS WHEN WE START BUILDING AND OPERATING STRUCTURES WHERE THEIR PROPERTIES CHANGE DYNAMICALLY ON THE BASIS OF NEW AND AS-YET-UNFORESEEN INTERACTIONS?
> ”

“All of a sudden the bridge began to rock. We were afraid the truck would turn over, so we … jumped out. We could only crawl on our hands and knees and got about 10 feet away when the truck fell over … We crawled along hanging onto the ridge of the center of the roadway … Chunks of the concrete actually burst out of the bridge deck as it swayed, groaned and buckled. I fell dozens of times on the pavement … I was ready to give up … One of the lampposts just did miss my head. Sometimes I was sure we'd never get off the bridge … I kept thinking that this bridge was something that couldn't break. It had been inspected by government engineers. And experts had planned it so it would stand any strain”.[1]

This is Ruby Jacox's eyewitness account of the collapse of the Tacoma Narrows Bridge in 1940. Ruby's story is an intimate and highly personal description of a terrifying experience in which she asserts her expectation of engineers and makes real the consequences of failing to live up to those expectations.

80 years later, the Tacoma Narrows bridge collapse is still used as an iconic lesson in physics and structural engineering. The bridge collapsed because of aeroelastic flutter, an interaction between aerodynamics and structural dynamics. Wind caused oscillations large enough to undermine the structural integrity of the bridge. The physics of the Tacoma Narrows bridge collapse, and its engineering implications, changed forever the way that engineering was theorised, practised and taught.

But the Tacoma Narrows bridge collapse has other lessons for us. It is a story of engineering practice outstripping theory; of the profession failing to notice that previously disparate areas of expertise needed to combine; and it's a salutary lesson in the need for the engineering profession to remember its fundamental value to society: technical trust at scale. These are lessons that we need to remember in 2020.

One could ask how the collapse came to be. One overly simple explanation is that design decisions were made to create a cost-effective and elegant structure which was unusually (and as it turns out, unsafely) long, narrow and flexible. But that's not the whole story.

The report of the investigation into the collapse suggests that it was a surprise that dynamic interactions between aero, mechanical and structural systems would be so important.[2] The investigation concluded that the bridge was adequately rigid for static forces, but “the criteria usually considered for rigidity against static forces do not necessarily apply to dynamic forces”. A key finding was that “[f]urther experiments and analytical studies are desirable to investigate the action of aerodynamic forces on suspension bridges”.

Now think about 2020. Consider smart homes that you can control from your car; a manufacturing plant that's remotely operated; the fully autonomous railways for mines; or those disconcerting elevators that work out for themselves the optimum way to move you around inside the building.

That world will be nearly unrecognisable to structural engineers from the 1940s. But those examples don't yet necessarily mean a radical rethink of the profession. It's true that smart-homes consume a lot more electricity than traditional ones, which means that the static heatload calculations will change. But telling Alexa to turn on the air-conditioner for your kids while you're on the road to your 6pm meeting isn't likely to change the structural integrity of the house.

But, what happens when we start building and operating structures where their properties change dynamically on the basis of new and as-yet-unforeseen interactions? For example, complex structures that can sense and actuate load on structural members in real-time to improve energy efficiency, comfort, economics, aesthetics, convenience or some other performance measure? In this IoT world, the network of sensors and actuators is likely to be mind bogglingly huge, involving devices embedded in the structure as well as the digital exhaust of people in the vicinity. So, the real-time feedback is going to be based on machine learning of terabytes of data and the behaviour of people. Let alone thinking about the properties of the 5G network in which it's all embedded. This is a complex, heterogeneous system-of-systems where not only do the sub-systems interact with each other, but they will do so dynamically.

Sound familiar?

Getting this right will draw on structural engineering, control engineering, data science, thermal engineering, materials engineering, energy engineering, anthropology, sociology, psychology and telecommunications engineering at least. It's unreasonable and probably unnecessary to expect that every single engineer be expert in all those areas. But it's entirely reasonable and certainly necessary to have a cohort of engineers who understand and can design a world where previously unconsidered interactions between those phenomena will be important.

One of the investigators of the Tacoma Narrows bridge collapse said:

“The Tacoma Narrows bridge failure has given us invaluable information … It has shown [that] every new structure [that] projects into new fields of magnitude involves new problems for the solution of which neither theory nor practical experience furnish an adequate guide. It is then that we must rely largely on judgment and if, as a result, errors, or failures occur, we must accept them as a price for human progress.”[3]

But I return to Ruby Jacox. The engineering profession broke trust with her. This isn't just Industry 4.0, it is our lived experience. We can see that this new world is coming. Think about fake news, post truth, Brexit, 737 Max, … We are betraying the trust that society puts in us as a profession if we wait until there's a catastrophic failure. We must lift the traditional engineering and computing disciplines up to a systems level, learning about the important interactions between traditional areas of expertise and how to bring in understanding about people. It behoves us to act now. That's what we at the Australian National University are embarking on right now. Come join us.

1 “Tacoma Narrows bridge eyewitness accounts”, https://www.wsdot.wa.gov/tnbhistory/people/eyewitness.htm accessed 12 November 2019.

2 David P Billington, “The tower and the bridge: The new art of structural engineering” p 37.

3 https://authors.library.caltech.edu/45680/1/The%20Failure%20of%20the%20Tacoma%20Narrows%20Bridge.pdf accessed 10 November 2019.

Will the **2020** engineer please stand up?

Trish White

> TO BE AN ENGINEER OF THE FUTURE, YOU NEED TO IMAGINE WHAT IS POSSIBLE AND BRING TO YOUR PROBLEM SOLVING AN AGILE CREATIVITY THAT IS APPLIED WITH A HUMAN LENS.

To be an engineer of the future takes more than good ideas, training in disciplined processes and an understanding of how things work. To be an engineer of the future, you need to imagine what is possible, have courage to reach out to people and technologies you do not currently know, and bring to your problem solving an agile creativity that is applied with a human lens.

So where will we find these engineers of the future?

For a very long time we have sourced our engineers in a very "Industry 2.0" type of way. Attentive parents inspecting the height and complexity of their three-year-olds' Lego structures sagely identify the budding practitioner—"Jamie's a natural engineer", they predict. We then look to school children showing aptitude in the "science" of engineering, narrowing our focus to those good at mathematics and the physical sciences in order to create our talent pool of potential engineers.

By the time our engineering pipeline gets to the university gate, we find few school-leavers have studied the pre-requisite school subjects for entry into engineering courses, let alone made the commitment to an intensive four-year engineering degree.

What if, perhaps, we took instead a design thinking approach to the problem? What if we started with the grand challenges of our time—improving human health, or finding better solutions to sustainable energy provision, or making our cities function more effectively? What if we thought about our users, their needs and the insights we could bring to solve their problems, and then work backwards to design the type of engineer perfect for the task? It would be someone with the capacity and competence to challenge the assumptions implicit in that which already exist, someone with the creativity to innovate for a better solution, someone with the determination to make sure their approach works.

Where would we look for our engineering talent pool if we took that approach? For a start, we would pay more attention to the people with aptitude for those skills who are already in, or motivated to enter, our workforce. We'd identify the capabilities we need to solve the engineering challenges and look for those who would mean for us the best fit to bridge any capability gap we face. Of course, ours would not be a single pipeline that denies those who miss the school entry-point, forever reminding them of their lesser status to the anointed. We would look broadly and inclusively, with keen attention to developing the young but at the same time focusing on the opportunities that present with the experienced.

We'd also think of ways to build the competencies for the future into our business and organisational approaches. We'd think of this for our engineers not as a one-time achievement of a credential or two, but as a journey of insightfulness through important touchpoints that build upon each other in a way that adds up to much more than the individual parts. We would know that some competences take a long time to build and some can be gained usefully in short engagements.

Industry 4.0 Higher Apprenticeships (that bridge the current gap between technical training and university education) is an example of programs that widen the enrolling demographic. This program focuses keenly on the practical competencies required by the advanced manufacturing sector in our Industry 4.0 world. Co-designed by industry and academia to ensure relevance, with integration of trade skills into higher-level qualifications in Industry 4.0 technologies and accredited through an Associate degree (from Swinburne University), the program gives participants first-hand work experience to ensure development of practical workplace skills.

Similarly, recent approaches to STEM programs in schools by Engineers Australia and others seek to present engineering problem-solving in a much more attractive and practical way, and the advent in a small number of Australian schools of "engineering" subjects is aimed at ramping up both the interest and preparedness of our potential engineers. The starting point for these engagements is the real-world challenges that we as humans care about. The scale, scope and gathering pace of Industry 4.0 transformation is changing the nature of engineering work and placing engineers front and centre as key influencers shaping our future society. So, if our starting point is the problems that companies and organisations are trying to solve, then what are the important shifts in the nature of engineering work arising with Industry 4.0 and what implications are there for our engineers of the future?

For a start, all engineers will need to know the digital world; uptake of smart automation, artificial intelligence (AI) and virtual / augmented reality within industry is prioritising a new required skill set with new data analytical capabilities also rising in importance. Employers expect engineers to have deep technical skills but they also want their engineers to be able to reach broadly to find the best technologies and know how to bring them into a venture, to be able to innovate and communicate well. Communities are demanding "smarter" infrastructure, products and services. In that context, the job of today's engineer is more than delivering to a specification on time and on budget; it's about influencing outcomes for projects that make a difference to people's lives. Customer and user focus is central in the Industry 4.0 environment of customisation and personalisation.

While advanced technologies are becoming more accessible, engineers must also apply an ethical lens. Last year at the Australian Engineering Conference hosted by Engineers Australia, Geoffrey Robertson QC ran a provocative "hypothetical", which caused engineers to think deeply about their own biases when building the algorithms that will control robotic machines which might love, think, care for the ill, or kill.

It's important that engineers step forward to take responsibility and use their influence for better societal outcomes as they contemplate how to organise the interface between machine and human. Engineers must step forward to influence decision-making in delivery of an Industry 4.0 future, because if they sit back, the "possible" will play second to the convenient.

TRISH WHITE

SENIOR LEADER/ ADVISER/ RESEARCHER/ COMPANY DIRECTOR/ MULTIPLE CAREERS IN POLITICS, ENGINEERING AND LEADERSHIP/ PAST PRESIDENT OF ENGINEERS AUSTRALIA

PETER CEBON

RESEARCHER/ FACILITATOR/ TEACHER THRIVING AT THE INTERSECTION OF INNOVATION, MANAGEMENT AND ORGANISATIONAL DESIGN

The importance of the socially conscious **engineer**

Peter Cebon

> AT THIS POINT, THEY REALISE THAT MANY OF OUR CONTEMPORARY PROBLEMS WERE CAUSED BY EARLIER ENGINEERS, WHO, LIKE THEM, BELIEVED THEY WERE SOLVING THE WORLD'S PROBLEMS.

If you ask students if they are studying engineering to help fix many of the world's problems, a significant proportion raise their hands. If you then ask them whether the same problems were created by engineers, many of those hands stay up. At this point, they realise that many of our contemporary problems were caused by earlier engineers, who, like them, believed they were solving the world's problems. They then wonder what impact they will really have. This raises questions about the intrinsic value of technology. The deeper thinkers among them realise that technology is neither good nor bad. However, it isn't neutral either. Rather, technology, and its evolution, is shaped by the interests of those who specify it. Our socio-economic system favours some projects and interests over others.

The usual admonition at this point is to teach engineers about ethics. I believe this is necessary, but woefully insufficient. Few of the ethical choices associated with Industry 4.0 are obvious or unambiguous. Consider health trackers. Insurance companies can (and likely will) use their data in insidious ways. However, that final use is just the last link in a chain of questions that don't appear to be ethically significant—whether to monitor these human functions in the first place, whether to store the data in the cloud, whether to allow companies to mix these data with other data about users, and so forth. Further, one engineer, or 100,000 engineers, voting with their ethical feet and deciding to not work on these technologies will have absolutely no impact on the development trajectory. Thousands more see them as ethically virtuous.

It's really tempting, at this point in the discussion, to throw our hands in the air, declare this to be a social or political problem, rather than an engineering problem, and pass responsibility for the future of technology to some mythical "other". Unfortunately, that "other" doesn't exist. It is us, and those around us. Engineers must be central to these conversations, if only because they understand the technical aspects of many of these dilemmas. We must train the next generation of engineers to confront this emerging world. They must join the community conversation about the future of technology, both through their words and the artefacts they create.

The health tracker example points to two key skills, beyond ethics, that need to be central to engineering education. The first is the ability to think through complicated systemic problems. The engineer designing the dissolved oxygen sensor for the back of a watch must be able to locate it within a large ecosystem of emerging and converging digital, biological, and mechanical technologies, and consider the implications for that ecosystem of various design decisions. Engineering schools traditionally provide this skill, though rarely explicitly. It is critical that we maintain it.

The second is the ability to see their designs as sitting within a broader socio-technical system, and not as purely technical products. In the University of Melbourne's Innovation Practice Program, engineering students and students from other disciplines work alongside a mentor and a sponsor from a sponsoring organisation to develop a proposal for a product, service, or organisational change in response to an innovation opportunity presented by the sponsor. In so doing, they learn a number of things that start to prepare them to develop that ability. For one, they learn how to work in teams on ambiguous, conceptually challenging projects. They also gain insights into themselves, their motivations, and their careers. They also learn several things as a result of going through an innovation process. The process forces them to confront the idea that a professional's job isn't just technical, it is to create value, and that value is created for someone. Value is not independent of particular people. From there, it is just a small step to start recognising that every engineering project, more generally, redistributes value within the broader society, and that we have choices about how that redistribution occurs.

While the First Industrial Revolution created many more jobs than it destroyed, it took 80 years for that to happen. Before that, the effects were decidedly negative. Even then, the new jobs required essentially the same skills as the ones they replaced. Agricultural workers moved seamlessly into factory work. It took even longer for the social costs of these technologies—worker safety, pollution, and working conditions—to start to be mitigated through technological improvements and regulations. Likewise, many commentators believe the current lurch towards authoritarianism in many of our democracies is driven by us not understanding the macro-economic implications of the quality movement.

With globalisation, emerging economies were suddenly able to leapfrog the developed economies, displacing workers in manufacturing heartlands. As we move towards Industry 4.0, it would be foolhardy to assume that the adjustment is not going to be just as harrowing, if not more so. The people displaced are unlikely to be candidates for the jobs created; new jobs may not be created at the same locations as the jobs lost; new technologies will intersect with environmental, population, and socio-economic forces. Engineers will be central to creating that future. They must also actively participate in the social conversations around those technologies. If they do not, they will just create a future that reproduces and entrenches the interests of the powerful.

Observations of the **Fourth** Industrial Revolution

Gordon Wyeth

GORDON WYETH

RESEARCHER/ PROFESSOR AND ENGINEERING DEAN WITH A SPECIALISATION IN SPATIAL COGNITION AND BIOLOGICALLY INSPIRED ROBOTICS

> “WE NO LONGER NEED TO HAVE A WORKFORCE FOCUSED ON MATHEMATICS AND CALCULATIONS, BUT RATHER ONE THAT IS MUCH STRONGER IN ENGAGEMENT AND CREATIVITY, COUPLED WITH STRENGTHS IN THE UNDERPINNING SCIENCE.”

As a Professor of Robotics and a leader in engineering education and research, I've been keenly interested in Industry 4.0 and particularly in trying to understand the fundamental difference between the Third Industrial Revolution and the Fourth. I'd argue that the key difference is that the third was changing the industry to suit automation whereas the fourth is about changing automation to suit the industry.

Take Australia's two biggest industries for example: mining and agriculture.

Our biggest mining companies have gone digital in a big way, and continue to pursue the benefits of automation and data analytics. In the Third Industrial Revolution, trucks became massive, draglines became the largest pieces of machinery on the planet, and processes were fine-tuned by an army of engineers to get maximum productivity. Twenty years ago, the productivity gains started to flatten. Going bigger wasn't helping anymore, and industry started to focus on being smarter. There has been a lot of attention paid to automation of the big trucks (which I find very cool as a robotics professor!) But the real benefits have come from data about the mine and its processes that were necessary for the automation of the trucks. The automated trucks needed much better sensing and communication, which then gave much better data which in turn led to new insights into scheduling and optimisation. It is also starting to create new engineering possibilities in the way that mines themselves are constructed, as the dynamics of the mines are better understood and automated process and machinery create new possibilities. So the change in emphasis in mining is how do we set up processes to make the mine more productive, rather than how we change the mine to set up more productive processes.

In broadacre agriculture, the Third Industrial Revolution brought us the next generation of large scale agricultural equipment, with some efficiencies improved by scale and automation “in the small.” Tractors became bigger, the length of boom arms for spraying became longer, harvester heads were made cleverer, tractor cabins were air-conditioned, and the tractor gained features like cruise control and auto-steer. These advances still need a farmer to drive the machines and set the settings. Farms and farm practice changed to suit the bigger equipment and the broad processes that happen at scale across the farm.

Industry 4.0 might see the farmer out of the field and in a control room which creates a range of new possibilities. Fully autonomous tractors don't need to be bigger—driving is now hands-free, and you don't need to carry around a human (and the air-conditioning). The bigger tractor can now become multiple small autonomous vehicles. Sensing and data are now paramount, and making sense of that data is critically important. With multiple, smaller machines guided by data and analytics, each machine can fine tune its behaviour to the needs of specific areas within paddocks, maybe right down to the individual plant or even each leaf on the plant. The productivity and sustainability of the farm goes up—including the environmental sustainability. The automation is being designed to suit the long term needs of the crops, rather than farms being designed to suit the machines. This change brings a fundamental shift in our requirements for our agricultural workforce—we need less manual labour skills, less machinery operation capabilities and more scientific and analytical abilities to manage the changing landscape of the farm.

So what do observe in the engineering industry?

There was a 52% increase in the number of qualified engineers working in engineering occupations over the period from 2006 to 2016. We are seeing fewer and fewer engineering firms—exact numbers are hard to gauge but it is certainly clear that the numbers are not going up. In common with Third Industrial Revolution thinking, engineering has gone large—seeking economies of scale by bringing together engineering capability under one roof.

Automation of engineering design has certainly being going on for some time. I trained as a Computer Systems Engineering. At great expense to the tax payer, I learnt about logic minimisation using Karnaugh maps, how to implement state machines on flip-flops, and spent a lot of time laying out circuit boards with registers and buffers and all kinds of discrete logic. I also learnt skills in how to execute complex calculations by hand or using my HP-41C calculator. Nearly all of that training is now completely redundant. All of these tasks have been automated, or the technology has changed so drastically that the methods we learnt are no longer relevant.

One of my good friends who graduated as civil engineer spent his first five years hand designing weirs and dykes. His days were spent at the desk running the calculations and producing the drawings. This is not the kind of job you'd see in many civil engineering offices in Australia any more, having been either offshored or automated.

These are examples of the beginning of Engineering 4.0, and they bear some of the same characteristics of the other industries entering the Fourth Industrial Revolution. We have gone through a period of going large, and we are now looking at what processes can be automated. The benefits of automation will be hard to resist, and the nature of engineering work will fundamentally change. The requirement to sit quietly at a desk and perform mathematical calculations all day is largely gone from engineering work. The future of engineering is engaging with clients and creating designs.

This is going to be a big change for our workforce—we no longer need to have a workforce focused on mathematics and calculations, but rather one that is much stronger in engagement and creativity, coupled with strengths in the underpinning science and strengths in digital technologies. This is going to take a while to change. Think about the conversations that school career advisers are having with students. Do you think it goes “You're creative and engaging—you should do engineering!”? Unfortunately, it's much more likely to be “You're male and good at maths—you should do engineering!”

Maybe this is what has led to the disturbing statistic that less than a quarter of that 52% growth in the supply of professional engineers in Australia over the last five years has come from education completions. 76.5% of the growth in engineering has come from skilled migration. By far the dominant discipline for skilled migration is software—making up nearly a third of the migrant engineers.

There is no doubt that engineering skills are in ever increasing demand in this country, and that we are seeing increasing take up of software engineering skills in the mix. However, we still have a lot of work to do in projecting a new image of the engineering workforce if we are going to thrive as a nation in Industry 4.0.

The complementarity between

human enablers + digital innovation futures

Adela McMurray

ADELA MCMURRAY

RESEARCHER/ INNOVATION MANAGEMENT AND ORGANISATIONAL CULTURE SPECIALIST/ ENTREPRENEUR

"WE NEED CHAMPIONS OF NEW SYSTEMS WITHIN ORGANISATIONS, INDIVIDUALS WHO WILL HELP SHIFT FROM THE OLD WAY OF WORKING TO THE NEW."

Propelling ourselves into the reimagination of futuristic mindsets requires pushing the boundaries of disruptive innovations that compel us into entertaining, and ultimately engaging in, revolutionary attitudes and behaviours that sail into the unchartered waters of national and global leadership innovations.

In RMIT's 2019 national survey on corporate entrepreneurship and innovation across 1,415 Australian companies, they identified engineering as ranking 3rd for innovativeness out of 33 Australian industries. This finding acknowledges engineering as one of Australia's leading industries navigating the Industry 4.0 revolution. RMIT's finding could be attributed to the fact that engineers are decidedly committed to their work, enjoy relatively high autonomy and often behave in ways that do not conform.[1] They are unique and tasked with the production of innovation which contributes to society through the development of technological applications which enhance standards of living[2] thus leading to the development of new knowledge including new entrepreneurial opportunities and ventures. Engineers think differently compared to many other professionals and apply precise methods to problem solving (e.g., simulations, prototyping, scaling models) and often think in terms of systems and apply deep knowledge of technology, design, computation and the laws of physics.

To facilitate the best innovations of Industry 4.0, we need human enablers. What does this mean? We need champions of new systems within organisations, individuals who will help shift from the old way of working to the new. I'll give you a simple example that has likely happened at your organisation. Say your company wants to initiate a new software into your BAU responsibilities. A significant portion of the staff are resistant to this change because they must learn something new. Your organisation, wise to this, has put a system in place where champions of this new software ease the transition, ensuring a relatively error-free adoption of the new technology. These are the companies that are going to win in Industry 4.0 because they consider the human aspect alongside the technology, as the complementarity between the two is vital for success in our current industrial climate.

Human enablers that facilitate innovation within engineering contexts can be supported by the regular promotion of a vision (meaningful impact) and an employee's place within it.[3] Employees will be empowered to postulate what digital innovations might complement and support human elements and propel engineering workplaces into the multi-layered world of Industry 4.0.

A new generation of engineers is currently coming through the ranks and central to this new generation is data and analytics as core capabilities. There are many potential technology platforms that could support the human and technology complementarity. One exciting example which I think most can envisage, is the imminent implementation of an "engineering cam" trained on workplace project innovations in progress. This innovation could be implemented nationally to stream online and ultimately reach a global audience of engineers and engage in collaborative work-supporting tools.[4] A streaming app, complete with chat function, would facilitate real time data and analysis as it occurs throughout each stage of the innovation by matching tasks or projects with higher technological challenges and less stable requirements.[5] This digital innovation could support a network of elite engineers on a "digital engineering Facebook" where commentary, photos or videos could be provided. The "engineering cam" would enhance empowerment (greater control over tasks and workloads) and absorptive capacity.[6]

From the human component, enablers and structures such as the quality of the supervisor-subordinate relationship, managerial role expectations and stable long-range organisational goals and priorities must be anchored to management and leadership. Organisational climate is an antecedent to the development of the organisation's culture. Therefore, nurturing a highly innovative communicative climate is integral to leadership and management to promote workforce cultures that push innovation technology boundaries. This leads to the possibility of the "engineering cam" concept as potentially providing a fertile springboard for the Theory of Inventive Problem Solving (TRIZ). In this case, the "engineering cam" and app would facilitate multicultural and multidisciplinary teams to understand challenges effectively and generate ideas on how to innovatively solve them through a systematic approach. The innovations generated from TRIZ could be rewarded through the organisation's financial incentive program which enables higher quality innovations and a more valuable organisational intellectual property portfolio.[7]

The "engineering cam" would promote internal and external communication for companies to gain expertise in a specialised field. For example, in an intra-company collaboration, SRK Consulting scientists and engineers embarked in an internal and external knowledge sharing process to harness and advance their expertise in digital technology. They state "For SRK, this knowledge sharing internally and externally is a vital process for advancing our expertise by harnessing digital technology," … "It continually enhances the value of our offering to clients, while strengthening the economy's capacity to address challenges." Increasing digital innovation for SRK in the field of mining is critical because the geotechnical instrumentation and monitoring (GTIM) market is predicted to increase from USD 3.3 billion in 2019 to USD 5.0 billion by 2024.[8]

Finally, the global "engineering cam" and app, in promoting communities of practice generating deep knowledge across boundaries, could be used as a springboard to engage in the concept of digital thought leadership and design thinking where engineers extract insights from data to push innovation boundaries by fusing human enablers, design, engineering and technology. This could manifest itself into augmented reality, or the more advanced virtual reality technology, artificial intelligence (AI), distributed ledger technology, coding and computational thinking skills, or machine learning (ML) where each technology has the capacity to transform the way in which we live and work. The value chains that today's engineers generate into their digital business models and innovation cultures, will ruthlessly determine their competitive standing in Industry 4.0, which increasingly makes use of the industrial Internet of Things (IoT) and cyber analytic systems. The possibilities are endlessly exciting if we grasp this appropriately. In a succinct summation, the complementarity between these digital innovation elements combined with the matched capability of human innovation enablers is essential to propel the engineering discipline into leading the world's Industry 4.0 revolution.

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“MAJOR CHANGES TO ENGINEERING CURRICULA WILL REQUIRE A WHOLE-OF-CURRICULUM APPROACH, NOT JUST SMALL CHANGES IN INDIVIDUAL SUBJECTS.”

Shifting engineering curricula for **Industry 4.0**

Roger Hadgraft + Anette Kolmos

Climate change and Industry 4.0 demand new, more agile and employable engineering graduates, who are skilled in cross-disciplinarity, complexity, and contextual understanding. Our engineering programs will need to adapt. Engineering is of vital importance in achieving the Sustainable Development Goals (SDGs).[1] Industry 4.0 will involve widespread integration of automation, the Internet of Things (IoT), artificial intelligence (AI), robotics, advanced materials, additive manufacturing, and virtual and augmented realities.[2,3]

Engineering has not traditionally been taught in this integrative manner. Increased interdisciplinary collaboration is required between computer science, data analytics, robotics, automation, production, management, electronics, and materials. Innovation competencies, entrepreneurship and design thinking will be required. New engineering programs must integrate theory and practice through a focus on employability and collaboration with industry, using internships, partnership projects and learning labs.

Increased emphasis on social responsibility, integration of societal context and interdisciplinarity will be combined with digital and professional skills. These responses are essential for students to learn the fast-changing, specific skills needed for jobs in a workplace replete with tools of automation. Graduates need human skills, as well as technical understanding and systems-level insights that will be required in their new workplaces. Innovative solutions will be required that genuinely meet customer, client, and community requirements. Education must move from single discipline to multidiscipline, from simple and complicated to complex, and from a focus on technical skills to a focus on contexts, systems, sustainability and values.

Engineering programs have responded over the last 20–30 years through: student-centred learning, contextual and practice-based learning, digital learning and professional competencies.[4] Studies on active learning, inquiry-based learning, design-based learning, and challenge-based learning show positive effects on learning outcomes.[5] These results demonstrate that involving students in the decisions about their own learning process has a positive effect on their learning. Problem and project-based learning (PBL) are common solutions for more complex learning. Motivation rises further with student-initiated projects. This is particularly true with contextual, practice-related learning, including internships, industry projects, and innovation hubs. Digital learning, including the flipped classroom, will increasingly use new technologies for learning, such as augmented reality, 3-D visualisation, etc.[6] Technology is also a key support for student-centred, project-based learning.

Bringing all this together, is the move to individualised learning, where students track their own learning through the curriculum. They accumulate online mastery of topics and techniques and apply these skills in increasingly complex project situations. This combination of project plus individual learning path, we call a studio.[7,8] The future of engineering education will increasingly be personalised, with students actively engaged in mapping their own career path, choosing from a variety of studios and internships to develop their full range of competencies.[9]

Major changes to engineering curricula will require a whole-of-curriculum approach, not just small changes in individual subjects. Engineering academics will need to apply systems thinking and design thinking to develop these new curriculum models. Some examples are already available, though not yet widely adopted.

This article has identified the emerging trends for the future of engineering curricula in response to the three main challenges: sustainability, Industry 4.0, and graduate employability, requiring students to deal with complex problems using systems thinking in cross-disciplinary teams.

Four short-term trends include: student-centred learning, integration of practice, digital and online learning, and professional competencies. The emerging elements are a clear trend towards whole-of-curriculum planning, together with personalised learning, where students chart their own learning pathway choosing from a range of studios, supported by online content.

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> "THE CHALLENGE ACROSS THE INDUSTRY IS TO INTEGRATE PROFESSIONS, ELIMINATING ANY DIVISIONS WITHIN ENGINEERING TO CONTINUOUSLY CREATE INNOVATIVE SOLUTIONS FOR A WORLD IN RAPID TECHNOLOGICAL TRANSFORMATION."

Leading innovation and fostering belonging through Industry 4.0

Collette Burke

We are front and centre of the Industry 4.0 evolution taking place around the world right now. New technologies, including artificial intelligence (AI), 3D printing, satellite, renewable energy technologies, robotics, big data and the Internet of Things (IoT) are transforming our engineering processes. Digital technology could contribute up to $250 billion to Australia's GDP by 2025, based on technology that is currently available alone. These advancements are timely, since projects are becoming increasingly complex and expensive. Leading these innovations, and integral to their development, are engineers.

As the production and distribution of goods and services is transforming, the infrastructure of every city will need to adapt. The challenge across the industry is to integrate professions, eliminating any divisions within engineering to continuously create innovative solutions for a world in rapid technological transformation. The impact of this transformation on Victorians is exciting and evident across the state, from continuous glucose monitoring for patients with diabetes to facial recognition at international airport smart gates.

In a global environment of change, forward-thinking initiatives are a cornerstone for Victoria's continued economic growth. Here in Victoria, we are the powerhouse of manufacturing in Australia, operating a $26 billion industry and employing over 260,000 people. Through Industry 4.0, advanced manufacturing is at the forefront of the Victorian economy and spearheading the development of future industries. For the transition from automotive manufacturing, the Victorian Government's Future Industries initiative is supporting our economy through expanding the space, defence, food, construction, transport, biotech and energy sectors. This will enable Victoria to remain internationally competitive through creating the strategic planning to build our advanced manufacturing capabilities.

Some examples of the industry innovations being supported by government include sleepers developed and tested by the Monash Institute of Railway Technology in partnership with Sustainability Victoria. The sleepers are made from recycled composite plastic, which have been installed on Victoria's Metro Trains Melbourne and regional V/Line tracks. They are an alternative for the current timber and low-profile concrete sleepers and are more sustainable and less carbon intensive to make. For every kilometre installed, the sleepers use 64 tonnes of plastic waste that would otherwise have gone to landfill. This shows Industry 4.0 is driving smarter and more sustainable transport solutions to be developed and adopted.

Technologies include automated connectivity, autonomous driving, electric and hybrid vehicles, zero emission alternative energies and energy storage (e.g solar or hydrogen fuel cells), functional materials, and advanced light-weight structures. All these technologies contribute to the realisation of user-centric, safe, sustainable and connected transportation of people and goods. These technologies, which depend on knowhow and expertise across multiple engineering disciplines, are developed and taught in Victoria. This is a remarkable feat and we need to foster their growth in our fast-paced new world. To do this we also need an agile and inclusive workforce that work across disciplines and historical boundaries.

Engineers across Victoria will need to implement strategies like real-world simulation to better improve the way engineers learn with exposure to the changing technologies. Some pathways are already being applied. Led by AiGroup, with Swinburne University as the education provider and Siemens as the industry partner, the Industry 4.0 Higher Apprentice Program prepares students for jobs that are emerging in the digital economy. It combines elements of an apprenticeship and a higher education degree. The apprenticeship-style program involves training students in cutting-edge manufacturing technologies including 3D metal printing, automation, machine vision and virtual reality.

This is what educating our future engineers looks like and needs to entail to make sure we have the skills to keep fostering a prosperous Victoria. The demand for STEM capabilities to support engineering will be critical for a sustainable workforce. Initiatives being implemented to create the foundation for the leaders of the future include the Education State agenda and the Primary mathematics and science specialists initiative.

It is imperative to rethink and reimagine our learning experience and upskill our teachers from the grassroots level because teachers get the best out of our students and ensuring quality teaching helps every child achieve their full potential. In a world where the rate of change is developing at staggering proportions, we need to make sure we invest in our people, our training and ensure we create environments for the community to thrive and feel a strong sense of belonging.

PETER RATHJEN

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ANTON MIDDELBERG

SCHOLAR/ UNIVERSITY LEADER/ INVENTOR OF NEW TECHNOLOGIES

> "IN AN INCREASINGLY COMPLEX WORLD, STUDENTS DESERVE TO HAVE MULTIPLE PATHWAYS TO TECHNOLOGY CAREERS AND MULTIPLE POINTS OF SPECIALISATION."

Aligning engineering education to **embrace disruption**

Peter Rathjen + Anton Middelberg

When considering the future of engineering it is clear that organisations must embrace change, manage through disruption, and create dynamic and adaptive cultures able to deliver competitive advantage. At the University of Adelaide, we are adapting to this reality; education is aligned with the creativity and power of research to develop a workforce defined and valued for its intellectual flexibility and rigour.

Already the maturation of artificial intelligence (AI) coupled with powerful GPU-based computational platforms able to assemble, fuse and interrogate large data sets for meaningful insights, provides unparalleled opportunity. Through 3D design software, engineers can design and simulate multiple characteristics of a given device in almost real time. Once a design passes aesthetic and functional tests, modern additive or highly automated subtractive manufacturing can rapidly convert the virtual to reality, allowing the original digital product designs to evolve rapidly.

In this new world, educators can no longer focus solely on component design but must challenge their students to consider product and system design—to think about life cycle considerations, the product impact in and on society, and the likelihood of acceptance of the product. An engineer undertaking product design in a digital engineering platform will of course be technology literate—but armed with a degree from the University of Adelaide, they will also understand the implications of their product for society and for our world.

Launched earlier this year, our new *Future Making* strategy redefines the very role of a university to one of relevance—to industry, society and to people. We believe and assert that our efforts must be directed toward global challenges, with strong industry engagement. Our industry engagement priorities include energy, defence, health, agriculture and culture—all key industries for our state and nation. We listen to industry, and adapt to what we learn.

Future Making recognises that the application of knowledge is impacted by technological change and that key proficiencies from across the university must permeate research and educational activities. We are establishing virtual "colleges of expertise" to broker capabilities such as the transformational impact of artificial intelligence and big data provided by the University's world-leading Australian Institute for Machine Learning (AIML) and matching them with wider research and educational ambition. We are moving to a new educational paradigm where every graduate from the University of Adelaide will be equipped with skills in key areas—society, technology and sustainability.

Does this mean that our engineers will become too broad in their focus? On the contrary, we are actively encouraging a deepening of the fundamental skills that enable the best engineers. In particular, we recognise the importance of mathematics as an enabler of engineering. The University of Adelaide has as a prerequisite for its engineering degrees the completion of two subjects of mathematics at year 12. However, the number of people choosing to do two subjects of maths in high school is declining.

ATAR has for too long been a single defining number divorced from the skills that will ensure success in a university engineering course. To address this problem, we admit students for attainment in select subjects at year 12. Students achieving at least a B in each of the two Year 12 maths subjects, along with at least a C in physics or chemistry can enter engineering irrespective of their ATAR score. Anecdotally, this signal has already reached students entering high school, and their parents. It seems this shift from a single ATAR score is already influencing school subject choices toward those that give the right foundations for success.

As we alter the structure and content of engineering degrees, we believe that there is demand for a truly broad technologist role to complement engineering. We have introduced a new three-year Bachelor of Technology degree, which is specific to a given sector (e.g. defence). This degree draws in content from multiple engineering domains, and is deliberately broad, but still maintains depth. Each degree is designed in close consultation with industry—we start by listening to future employers.

As we progress students through this degree we wonder if it has the hallmarks of the liberal technology degree of the future. A young student leaving school may not wish to commit to being a specific type of engineer, but might prefer to understand multiple domains, e.g. mechanical, cyber and electrical design. They can then choose to specialise further, perhaps after commencing their career. In an increasingly complex world, students deserve to have multiple pathways to technology careers and multiple points of specialisation.

We anticipate there will always be a need for specialised engineers, who are suitably rounded and relevant to society, and understanding of our world. We also see an increasing need for pathways for students who value STEM, and aspire to technology careers, through less traditional and prescriptive pathways. *Future Making* sets out a path to ensure that our curriculum is matched to the future needs of learners and that our graduates are able to seek a broader range of career paths, positioning them for an advantage in the workforce of the future.

Random thoughts of a **world engineer**

Yee Lee Cheong

YEE LEE CHEONG
(DATO LEE)

UNITED NATIONS AND UNESCO LEADER/ MALAYSIA BASED/ FOUNDING PRESIDENT ASEAN ACADEMY OF ENGINEERING TECHNOLOGY/ RESEARCHER AND DISRUPTIVE THINKER THAT ADVOCATES FOR DIVERSITY IN STEM

In 2015, there occurred three seminal global summit conferences, namely the "Conference on Financing for Sustainable Development", July, Addis Ababa; "UN General Assembly" to adopt the UN Post 2015 Development Agenda, September, New York; and "Conference on Climate Change", December, Paris. The first Conference committed all UN member nations to allocate adequate funding and development assistance to achieve the 17 UN Sustainable Development Goals (SDGs) by 2030. The nations of the world committed themselves to reduce carbon emission and reduce global warming to pre-industrial levels in the Paris Climate Accord.

There was great optimism at the end of 2015 that the world was at last united to tackle the global challenges as posed by the 17 UN SDGs. It was acknowledged that science, engineering and technology, particularly engineering, will be key in providing the solutions. By the beginning of 2017, the euphoria evaporated with President Trump's "America First" policy and the US withdrawing from international agreements, including the Paris Climate Accord.

It is now left to the developing world to do their utmost to achieve the SDGs by 2030 by South-South cooperation. This will pose even greater challenge and pressure to the ingenuity of engineers in the South to come up with urgent and cost effective solutions maximising the use of indigenous resources and traditional knowledge and expertise.

The fact that we are also in the era of Industry 4.0 provides both great challenges and opportunities. Klaus Schwab, Executive Chairman of the World Economic Forum (WEF), proclaimed the coming of this revolution in Davos January 2016 thus: "The possibilities of billions of people connected by mobile devices, with unprecedented processing power, storage capacity, and access to knowledge, are unlimited. These possibilities will be multiplied by emerging technology breakthroughs in fields such as artificial intelligence, robotics, the Internet of Things etc." I would suggest what he proclaimed is in reality the Digital Revolution. He also characterised the Fourth Industrial Revolution as the most disruptive in human history. He highlighted two aspects: greater wealth disparity and massive job loss.

WEF forecasted in 2016 that in the next five years, there will be a net loss of over five million jobs. Whilst there will be new two million jobs created in digital industrial and services sectors, there will be a seven million job loss in the traditional industrial and services sectors. I suggest the new digital technology related jobs will mainly be filled by those with engineering education and training.

Whilst the need for engineers and engineering technologists has never been greater, there is an alarming decline in engineering enrolment in universities and colleges in the West. The shortage of engineering human resources is made worse by the inability to attract females into engineering. Of all the science related courses in tertiary education, the gender imbalance is worst in engineering! To me, that will have a disastrous effect in the achievement of the SDGs by 2030 if the world cannot make full use of the capacity and capability of an entire sex.

One possible solution is the promotion of STEM education from kindergarten upwards. An urgent review of STEM and engineering education is needed. In this review, we must take into account the disruptive impact of the Digital Revolution on education demonstrated by:

Top billionaires who did not have university degrees:

- **Bill Gates** *(Harvard, Computing)—Microsoft*
- **Larry Ellison** *(Chicago, Computing)—Oracle*
- **Mark Zuckerberg** *(Harvard, Computing)—Facebook*
- **Sheldon Adelson** *(City College New York)—Las Vargas Sands*
- **Michael Dell** (Texas)—Dell
- **Steve Jobs** *(Reed College, Calligraphy)—Apple*
- **Ralph Lauren** *(Baruch College, Business)—Luxury Brand*
- **Jack Dorsey** *(New York Engineering)—Twitter*
- **Noah Glass** *(Software Developer)—Twitter*
- **Biz Stone** *(Massachusetts)—Twitter*
- **Ted Turner** *(Brown University Economics)—CNN*
- **Michael Lazaridis** *(Waterloo, Engineering)—Blackberry*

Top billionaires who did not have PhD degrees:

- **Jack Ma** *(Hangzhou, English Language)—Alibaba*
- **Jeff Bezos** *(Princeton, Engineering)—Amazon*
- **Larry Page** *(Michigan & Stanford, Engineering)—Google*
- **Sergey Brin** *(Stanford Computing)—Google*
- **Naryana Murthy** *(ITT Kanpur, Engineering)—Infosys*
- **6 Partners** *(Engineering)—Infosys*

As digital technologies upgrade themselves one generation every two years in accordance to Moore's Law, young innovators cannot afford to wait for a PhD or even a bachelor degree. They must bring the fruits of their innovation to market as soon as possible. In this respect, one would assume they prefer to have a billion or hundreds of millions in US dollars rather than a university degree.

I would advise engineering faculties to venture into lifelong continuing professional development courses. This will be in line with the demands of the fast changing digital age.

One of the cardinal reasons in failing to interest and attract children and youth to STEM and engineering is the failure of the global engineering community to put a human face to engineering! We continue to proclaim to the world our engineering structures and systems, rather than the engineers that design and build them.

We forget that children and youth need human icons to inspire them to pursue engineering. For example, the book *The Jewels in China's Crown* published by the Foreign Languages Press, China in 2018 documents China's engineering achievements in aerospace, high-speed rail, bridges, supercomputers, and new energy. There are very impressive photographs of China's achievements in the above five sectors, but not one photograph of the engineers who design and build them!

Perhaps China does not require such human icons. Engineering is attractive enough in China.

My icon is Nobel Laureate Sir Charles Kuen Kao of Hong Kong, the inventor of optical fibre. Optical fibre cable network is the backbone of broadband internet. Currently, there are over 400 submarine cables in service, stretching over one million kilometres around the world.

I have now cast aside the modesty of the engineer by projecting myself as a role model as promoted by my scientist friends.

I was one of three non-Muslims included amongst outstanding Muslim scientists for my advocacy of the science, engineering and technological achievements of the Golden Age of Islam from 7th Century to 14th Century A.D. that lifted Europe from the Dark Age and sparked the European Renaissance.

I was included by being a champion of inquiry based science education (IBSE) that promotes learning by doing from kindergarten upwards to wean children and youth away from book and rote learning that reduces their inborn curiosity, the essential attribute for innovation in our digital age.

Of the ten champions, there are three Nobel Laureates:

- The late Leon Lederman, USA, the father of IBSE
- The late Georges Charpak, France
- Mario Molina, Mexico

Charpak was a civil engineering and Molina is a chemical engineer.

Apart from the above two, there are three other engineers in the list of ten:

- Wu Yu, China, chemical engineer
- Yves Quere, France, geological engineer
- Lee Yee Cheong, Malaysia, electrical engineer.

Needless to say, I am very pleased five of the ten are engineers.

MARK CASSIDY

ENGINEERING DEAN/ INVENTOR AND INNOVATOR FOCUSED ON OFFSHORE GEOTECHNICS AND CIVIL ENGINEERING/ RESEARCHER WITH A PASSION FOR THE OCEAN

TUAN NGO

RESEARCHER/ AWARD-WINNING PIONEER IN CONSTRUCTION 4.0 AND PREFABRICATED HOUSING/ EUREKA PRIZE FOR OUTSTANDING SCIENCE IN SAFEGUARDING AUSTRALIA

Using digital to **enhance** the future of infra-structure

Mark Cassidy + Tuan Ngo

The global challenge and urgent need for sustainable infrastructure

As Australia's third largest industry, the construction industry is one of the significant drivers of economic activity in Australia and comprises over 330,000 businesses nationwide. The construction industry operates in both the private and public sectors across three broad areas of activity, namely engineering construction, non-residential buildings and residential buildings. According to the United Nations, the urban population of the world has grown from 746 million in 1950 to 4.2 billion in 2018,[1] and is projected to be 6.7 billion by 2050. However, it is predicted that the coming decades will bring even more profound changes, with an additional 2.5 billion people to be added to urban areas by 2050. This equates to 70 million new people needing houses, roads, rail and utilities every year.

A challenge facing both governments and the private sector is how to supply infrastructure to meet the rapidly growing population of urban centres.[2] Lower cost and faster construction speed are required, as are affordable and sustainable outcomes that enhance the quality of life of urban dwellers. Cities will thereby require substantial investment in infrastructure, with PwC estimating at least $78 trillion in the next ten years alone. Cities also consume 75% of the world's natural resources and account for 80% of greenhouse gas emissions. Within that, buildings alone consume 40% of the world's energy and emit 30% of the world's greenhouse gases. The rapid expansion of the urban population will therefore have a significant impact on global demands for energy and natural resources. Cities are "ground zero" for meeting the globe sustainability and climate change challenges.

The integrated and compact design of transport, infrastructure and land use is at the core of providing a foundation for a truly sustainable city. Denser, well-planned living is more efficient and creates a far lower cost than a sprawling suburban city. Additionally, these types of cities are also healthier places to live, imposing a lower burden on healthcare and other services.

Facing these challenges, there is a growing realisation that traditional construction techniques and practices will not scale sufficiently to supply future housing and infrastructure at an affordable cost. This is in addition to meeting the challenges of population growth, urban renewal, densification and sustainability. There is a need for the development of disruptive construction technologies that will make a step change in how future cities are built and current cities renewed.

Key challenges facing the construction industry

The construction sector is one of the largest in the world economy, with about $10 trillion spent on construction-related goods and services every year. Notably, construction is one of the major industries in Australia. Total construction activity in 2018-19 was valued at $220.8 billion.[3] Engineering construction was the largest sector (41.9% of all construction activity in 2018-19) followed by residential building (35.2%) and non-residential building (22.9%).

Approximately 383,326 businesses were registered as operating in the construction industry in 2017-2018. The industry has a small number of large firms and a long tail of small and microbusinesses in the supply chain. This industrial make-up poses significant challenges for transformation of the construction industry. Furthermore, the nature of workforce utilisation (teams assembled on a job-by-job basis) creates further inefficiencies.

Globally, construction sector labour-productivity growth averaged only 1% a year over the past two decades, compared with 2.8% for the total world economy and 3.6% for manufacturing. In the past decade, less than 25% of construction firms matched the productivity growth achieved in the overall economies where they work. Without change, the expanding global need for infrastructure and housing will be hard to meet.

Prefabricated construction and its transition into Industry 4.0

As a major initiative, the Melbourne School of Engineering (MSE) at the University of Melbourne has embraced an affordable, resilient and sustainable infrastructure vision for the future of building construction that is based on a manufacturing approach to construction including digital design, new materials and automated off-site manufacturing. Our team at the ARC Centre for Advanced Manufacturing of Prefabricated Housing (ARC-CAMPH) has engaged widely with industry and has rapidly grown MSE's funding base. Consequently, MSE has ascertained that prefabrication in the construction industry is already delivering substantial benefits.

However, prefabricated construction can become even more efficient, achieve higher quality products and reduce waste if it adopts proven methods and technologies developed and fine-tuned over decades in the automotive and aerospace industries. In these industries, digital prototyping and design for manufacture are deeply embedded within the supply chain. So too are automation, robotics and lean manufacturing techniques. Design, manufacture and assembly is so integrated and streamlined, production lines can be set up anywhere in the world where it is economic to do so.

An extension of these concepts has become known as Building Industry 4.0. This is being driven by digitisation and integration of vertical and horizontal value chains, digitisation of product and service offerings and the development of new digital business models and customer access platforms. A recent PwC industry survey concluded that engineering and construction companies are embracing Industry 4.0 concepts. They found BIM and the integration of design and off-site component-based assembly are evolving fast. At the same time, new innovations offer future integration and productivity opportunities and the increased ability to monitor assets over the life cycle rather than just at the construction phase. Autonomous vehicles can provide driverless transportation of materials between sites and on-site. Flying robots and drone surveillance offer the prospect of easier planning, design, monitoring and execution of projects as well as use in repairs and maintenance activities.

The digitisation, integration and automation opportunities enable companies to collaborate both internally and across their value chains in ways that can provide a step change in productivity as well as design and build quality. These opportunities are increasingly important as companies seek to stay relevant as the era of digitally connected smart infrastructure develops. Product development and engineering is the area where engineering and construction companies are furthest advanced down the digitisation and integration road. Digital solutions include features such as 3D modelling, construction sequencing, and progress monitoring and virtual rehearsal.

Industry 4.0 concepts can also reach further into the built environment with the advent of built-in sensors and automation enabling engineering and construction companies to develop products and services that cover the life cycle of buildings and infrastructure assets, integrating with energy management, repair and maintenance and wider smart building and smart city applications. Most importantly, it has been estimated by McKinsey and Company that by taking a manufacturing approach to construction (including digital design, new materials and automation) productivity in some sectors of the industry can be boosted by five to ten fold.

MSE is dedicating significant efforts to automated construction through advanced manufacturing by developing a one-stop-shop testing laboratory at its new engineering and design campus to be located at Fishermans Bend in Melbourne, Australia. It will provide certification on components and materials. The success of major developments involving prefabricated infrastructure is not only a function of the product produced and delivered but also of urban planning that takes advantage of the opportunities that prefabrication offers and the availability of cost-effective financing.

1 https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.

2 http://cdn.aigroup.com.au/Economic_Indicators/Construction_Survey/2015/Construction_industry_profile_and_Outlook.pdf.

3 https://www.masterbuilders.com.au/MediaLibraries/MB/Forecasts/2019-Jan-Master-Builders-Australia-Forecasts-Australia.pdf.

JIA-YEE LEE

RESEARCHER AND MULTIDISCIPLINARY CONNECTOR FOCUSED ON BIOMEDICAL ENGINEERING, HEALTH AND INNOVATION/ MENTOR FOR START-UPS

> SOLVING 21ST CENTURY CHALLENGES WILL REQUIRE COMMITMENTS FROM ACADEMIC INSTITUTIONS TO EVOLVE THEIR RESEARCH, TEACHING AND EDUCATION TO EMBRACE TRANSDISCIPLINARY APPROACHES.

Engineering a healthier future with the next generation of transdisciplinary engineers

Jia-Yee Lee

Why would a urologist, mathematician, and computer scientist huddle in front of monitors for several hours each week at Australia's Information and Communications Technology (ICT) Research Centre of Excellence? This is the world of personalised medicine that I found myself in when I was Director of Health and Life Sciences at National ICT Australia (now Data61). The team was pouring over mountains of genomic data from biopsies taken from the urologist's patients. They were hoping to discover the genomic drivers for high-risk prostate cancer.

This level of close-knit partnership would have been rare even at the turn of this century. However, healthcare is evolving and facing unprecedented challenges with an ageing population experiencing multiple chronic diseases, the growth in antimicrobial resistance, and emerging and re-emerging infectious diseases. Addressing these challenges requires a move away from the siloed approaches to problem solving. We must challenge the prevailing team-based composition and approach that is multidisciplinary or interdisciplinary (both terms tend to be used interchangeably) with each expert working within his/her own discipline while engaging those from another discipline (mechanical, electrical, civil, chemical engineering, computing and information systems, architecture, medecine and the the humanities).

21st century solutions that lead to improvements in the health of societies and the wealth of nations require a transdisciplinary approach that converges and integrates engineering and mathematics with computational, social, natural, physical and life sciences to tackle complex, multi-dimensional and multi-scale problems. The next generation engineer will require transdisciplinary capabilities to apply principles, fundamentals, and frameworks of two or more unrelated disciplines. A transdisciplinary engineer should be able to speak the language of another discipline and engage in developing new knowledge and methods, and new ways of thinking. Undertaking transdisciplinary research will give rise to new and emerging disciplines. In fact, transdisciplinary research has been "historically viewed as the pinnacle of evolutionary integration across disciplines."[1]

Biomedical engineering, a relatively new discipline within engineering, fosters transdisciplinary research, education and training. A biomedical engineer is well-equipped to understand the language of engineering, computing, biology and medicine. An example of transdisciplinary research and training is seen in the newly established Australian Research Council Training Centre for Medical Implant Technologies (ARC CMIT) that is led by The University of Melbourne. Funding from the ARC will support PhD students and early career researchers at The University of Melbourne, Flinders University and Griffith University to undertake industry and clinically driven research on personalised medical implants using 3D printed technology with a specific focus on orthopedic and maxillofacial implants. The ARC CMIT brings together biomedical engineers, scientists, and clinicians, and connects these experts with the global value chain providers of personalised implants from Australia, China, Belgium, UK and USA.

A tripartite coupling of industry-university-hospital collaboration could see Australia develop:

- smart implant systems with sensors embedded in 3D printed implants using the design principles of the internet-of-medical-things. Such implants will guide patients' rehabilitation, increase the longevity of implants and reduce surgical revision rates;
- new antimicrobial nanomaterials for implants to reduce the risk of infection and increase the longevity of implants;
- point-of-care additive manufacturing implant facilities for "Designed and Made in Australia" personalised implants.

Solving 21st century challenges will require commitments from academic institutions to evolve their research, teaching and education to embrace transdisciplinary approaches. In complement to this, industry should also foster a change in organisational culture to build transdisciplinary expertise and capabilities.

Acknowledgment

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[1] US National Science Foundation. https://www.nsf.gov/od/oia/convergence/index.jsp (accessed 15 December 2019).

Convergence and Collaboration

How might we most seamlessly and efficiently connect our increasingly sophisticated digital intelligence to the physical world?

Our most **precious resource** is no longer in the ground

Sally-Ann Williams

SALLY-ANN WILLIAMS

CEO/ ADVISER/ MENTOR FOR INNOVATION AND START-UP ECOSYSTEMS/ ADVOCATE FOR STEM EDUCATION, DIVERSITY IN STEM AND THE ROLE DEEP TECH MUST PLAY NOW AND IN AUSTRALIA'S FUTURE

> "I BELIEVE THAT FOR THE FIRST TIME IN HISTORY, AUSTRALIA'S NEXT GREAT RESOURCES BOOM WILL NOT BE FUELLED BY DIGGING ROCKS OUT OF THE GROUND, BUT INSTEAD BY DEEP TECHNOLOGIES."

It all began with an announcement in the Sydney Morning Herald.

Gold had (officially) been discovered in New South Wales! And just like that, a gold fervour was detonated which would transform the nation.

Real wages rose 70% in under a decade and the population quadrupled as migrants from across the world flocked to try their luck. Industries servicing and building infrastructure for the mines flourished, such as manufacturing, sawmilling, brickmaking and transport. Gold mining rose to around 35% of national GDP and helped pay for roads, schools, churches, and major train lines.

Such is the transformative power of a resources boom.

Historically, our resources booms have typically involved digging precious resources from the ground, such as gold, coal, and iron ore. As a result, our minerals industry is one of the largest in the world and remains one of the biggest contributors to Australia's export trade.

But for how much longer?

A new world order

I believe that for the first time in history, Australia's next great resources boom will not be fuelled by digging rocks out of the ground, but instead by deep technologies.

And there are three factors that will drive this change.

Firstly, the growing digitisation of the world's largest industries—infrastructure, manufacturing, transportation, agriculture, energy—is driving a growing need for deep technologies as the new inputs. Deep technologies are built on a foundation of substantial scientific breakthrough or high-tech engineering innovation. They cover areas such as advanced materials and manufacturing, artificial intelligence (AI), biotech, robotics, photonics, electronics, and quantum computing, which can all be applied in many formats across many unrelated industries.

Secondly, global industries are increasingly facing pressure to transform so as to begin addressing—and stop contributing to—the world's most pressing concerns. Deep technologies are not your usual "apps and marketplaces" style of innovation. Instead, they are capable of radically transforming whole industries, or even creating entirely new ones.

Where former resources booms have contributed to environmental degradation, as one example of negative externalities, deep technologies can instead help to solve the world's biggest problems as defined within the framework of the UN Sustainable Development Goals (SDGs). These include issues such as climate change, food security, water supply and sanitation, health, gender equality, and energy supply. Addressing these issues will become increasingly central to the long-term viability of all companies and industries, as driven both by increasing need and also societal pressure.

Finally, these two "demand" factors will combine with a third "supply" factor. Australia produces an abundance of world-leading research and IP, and we know how to commercialise it. Studies suggesting we rank last in the OECD for research/business collaboration are based on survey methods measuring the perceptions of business leaders, not data on the number or success of these collaborations. Nor do they include the input of universities.

And the more we see stories proclaiming Australian universities don't collaborate with industry, the more we perpetuate these incorrect perceptions. The reality is there are successful research/industry collaborations hidden across the country like veritable nuggets of gold, which can and must be emulated at scale. But to profit from these above three factors, it is critical we integrate and invest in the ecosystems that support the deep technology companies solving the world's biggest problems.

And we have evidence it is possible.

Case(s) in point

Take SDG #2: "End hunger, achieve food security and improved nutrition, and promote sustainable agriculture".

Cicada incubatee, InvertiGro, is working on a vertical farming solution that converts indoor spaces into highly efficient rural-scale farms capable of growing leafy and micro greens, berries, fruits, vegetables, and more. The farms are 95% more water efficient and yield 150 times more per square metre than traditional farming, use zero herbicides or pesticides, and production occurs 365 days per year. This will have enormous impacts on the reliable supply of fresh produce in any type of location, climate, and environmental conditions, such as high-density cities, remote locations, or even humanitarian crisis areas. Scaled globally, it could revolutionise food supply for billions of people.

Then there is SDG #9: "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". Cicada incubatee, Morse Micro, has developed a HaLow silicon chip that transmits Wi-Fi up to 1km using very little power, which is ten times farther than conventional chips and provides 100 times more coverage from a single access point. Because the chip can also securely connect more than 8,000 devices to one access point, it offers incredible implications for the Internet of Things (IoT) and Smart Cities.

The next global wave of job creation will be accelerated through the construction of the digital infrastructure that connects and digitises. This will enable intelligent, cleaner, and more efficient cities, energy provision, buildings, manufacturing, and agriculture, resulting in significant reductions in carbon emissions.

A word of warning

We might miss Australia's deep tech resources boom. Becoming a global supplier of the technologies driving these industries and addressing these issues requires specialised ecosystems designed to support the unique characteristics of deep technologies. These technologies take far longer to commercialise due to lengthy periods of R&D that often include field or clinical trials. They are capital and IP intensive, and demand larger, longer-term investment to achieve potential commercial success.

Building a deep tech business is an enormous feat, and success cannot occur without dedicated ecosystems that bring together investors, mentors, talent, customers, markets, industry partners, and government (as both customers and advocates). What we are doing at Cicada Innovations is a microcosm of what needs to scale at a national level with more investment from both the private and public sectors.

We would be remiss to forgo the opportunity of our lifetime because we remained focused on digging rocks out of the ground.

The conservative

high-trust profession of engineering must become more *active*

Yohan Ramasundara

YOHAN RAMASUNDARA

DIGITAL LEADER WITH GOVERNMENT FOCUS/ BOUNDARY SPANNING GOVERNMENT, INDUSTRY AND POLICY SECTORS

> "THE VERY COMPOSITION OF ENGINEERING MAY HOLD ITS ACHILLES HEEL–TOO MANY LIKE-MINDED, LEFT-BRAIN, SIMILARLY EDUCATED AND MAINLY MALE, PROFESSIONALS."

The enduring value of engineers remains in the name—it comes from the Latin "ingeniator," meaning one with ingenium, the ingenious one.

Engineers currently hold a well-earned high-status position in the community. The profession's ability to continue to attract bright young minds keeps it relevant and flourishing.

The engineering profession has progressed admirably through the pre-scientific revolution, industrial and second industrial revolution and the information age. Regulatory support and in some areas, a monopoly status, enshrines engineers as the trusted source of advice across many specialist areas. From this commanding position:

The greatest threat to the engineering profession is itself.

Complacency, government regulation or deregulation, competition, reduction in standards, profiteering, digital disruption, breaching trust and mis-reading public sentiment—have weakened or unravelled many industrial behemoths and occupations.

Facebook and Australian financial planners, major banks and the horse racing industry are currently under intense scrutiny. Occupations like farmers and even accountants and lawyers are feeling insecure. No occupation can rest self-assured.

Often, the entity itself, is least able to see and deal with emerging threats. Self-centred interests, especially in leadership circles, or cultural inertia and norms often blind fatefully. The very composition of engineering may hold its Achilles heel—too many like-minded, left-brain, similarly educated and mainly male, professionals.[1] Facebook and big banks are classic examples of the cost of cultural dissociation.

To maintain high public trust, the engineering profession must find more ways to: review itself regularly and independently; embrace diversity; address weaknesses accelerate cultural change and evolve.

Schumpeter coined the term "creative destruction" to describe how technological progress displaces old industries with creative new ones. In an increasingly tech-led economy, the engineering profession is well placed to continue being a major force for good.

Nevertheless, most innovation is being driven by start-ups and small companies with limited affiliations with larger bodies. The founders of many global IT companies never graduated, for example, Bill Gates and Mark Zuckerberg. Start-ups are focused on ideas, innovation, cash flow and capital raising at the expense of profession-driven courses, membership and codes of conduct.

Engineers must forge ever closer links with innovation sectors and find better and faster ways to assimilate and comprehend what's going on, or watch their status as a preeminent source of professional and trusted advice, dwindle.

Another threat is diminishing value. It will start in schools, progress to universities still designed along rigid industrial lines and conclude with mentors, drawn from senior ranks, but who find their value diminished by the impact of rapid change.

For example, fuelled by government cuts to funding, universities are seeking revenue by attracting more overseas and low-ATAR students, promoting courses with the best margins, softening academic standards. A subtle drain on the quality of engineering graduates is difficult to detect and counter.

Information technology, fast-evolving and the engine of creative destruction, has declining student numbers in Australia and an unhealthy course non-completion rate.[2] While enrolments have improved, the gap between supply and demand widens. The trend warns engineers that long fixed courses may no longer fit disciplines subject to rapid change.

The engineering profession must influence the institutions that educate tomorrow's engineers or create new pipelines that respond faster to the challenges ahead.

A growing pressure on engineers will be industry attempts to maintain profitability at all costs.

For example, investigations into Boeing and the crashes of 737 Max planes found the company put pressure on employees, like pilots and aeronautical engineers and cut corners.

Further, the engineers working for the US Federal Aviation Administration (FAA) were found to be deficient. The FAA also allowed Boeing to do compliance obligations normally performed by independent authorities.

The mantra of less regulation has dominated government thinking for decades. However, the more we pursue complex engineering and software endeavours the more engineers must be able to stand their ground.

The engineering profession must provide better ways to encourage engineers to report adverse matters and protect them from repercussions.

Further into the future, some predict the singularity will be reached—a point where technological growth is uncontrollable and irreversible. It is not in engineers' interests for this to unfold.

Engineers can be very proud of their profession. The profession's roots go back to Galileo's landmark publication, Two New Sciences. engineers remain ingenious in practice. Nevertheless, since the invention and use of the nuclear bomb, mankind continues to add more ways to obliterate life.

Even if the singularity does not materialise, Stephen Hawking and Elon Musk raised extinction-level concerns about runaway artificial intelligence (AI), as dramatised in the film *Slaughterbots*. Agnostic capitalism and a soulless tech industry are brutal instruments—consuming and disrupting with limited care.

The rate of change is accelerating exponentially and never been so globally impactful. Slow-moving institutions like government and the law must speed-up to better protect humanity from what we have unleashed. With safeguards, we can benefit enormously from our creative ingenuity.

"The optimist thinks this is the best of all possible worlds. The pessimist fears it is true".

— J. R. Oppenheimer

Conservative high-trust professions, like engineering, must step up and become much more active, vocal and influential globally if we are to steer wisely ahead.

If engineering's greatest threat is itself, its ultimate challenge is to protect life from creative destruction.

[1] Of personality type instruments, INTP is nicknamed Engineer's profile and 2.5% of all 16 personality types.

[2] Digital Pulse 2019, Australian Computer Society, p. 10.

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Will the

engineering industry please re-invent itself?

Graeme Henderson

GRAEME HENDERSON

INDUSTRY AGNOSTIC DIGITAL INNOVATOR/ MULTI INDUSTRY AND CONTINENTAL EXPERTISE AND EXPERIENCE

I would argue that the rate of physical infrastructure improvement in society is accelerating. By most measures, life is improving. Whether it is access to food and clean water, or shelter or education, and yes, even the latest digitally enabled roads and public transport system. The demand is unquenchable as we ask for more from our governments and the service providers of the economic complex. The benefits are large and increasing; but is this valid when compared with the costs incurred?

As an industry, infrastructure engineering (the design, construction and maintenance of infrastructure assets), in the broad sense, has been terribly inefficient. This is readily evident when compared to such industries as manufacturing and agriculture—this is well known and documented. So whilst engineers have been busy making other industries more efficient by streamlining and linking processes, by applying faster and larger unit processes and by thinking through the systems at play—our own industry has become less and less efficient, more wasteful, more expensive, less profitable and more competitive.

The basic reason for this is the level of thinking we, as a society, apply to spending the vast sums of infrastructure funding we have demanded. Instead of thinking about the system we use and its architecture, we drop down to a project-by-project approach. In other words, we think about the specific project and not about the system within which the project resides. Many people see waste as an opportunity—the inefficiency can be seen as a chance to uncover and retain "super profits"—this draws new competitors into the ever-growing budget allocations. This inefficiency also generates a super profit perspective, as suspicion on the part of the asset owner that causes projects to be put to the market in a fragmented manner, which in turn creates more inefficiency as more interfaces are created between different parties—the creation of a vicious and self-fulfilling cycle.

> "WHILST ENGINEERS HAVE BEEN BUSY MAKING OTHER INDUSTRIES MORE EFFICIENT BY STREAMLINING AND LINKING PROCESSES, BY APPLYING FASTER AND LARGER UNIT PROCESSES AND BY THINKING THROUGH THE SYSTEMS AT PLAY–OUR OWN INDUSTRY HAS BECOME LESS AND LESS EFFICIENT, MORE WASTEFUL, MORE EXPENSIVE, LESS PROFITABLE AND MORE COMPETITIVE."

This system we have created generates a perceived benefit to the industry because it has grown on the back of the overall market revenue growth caused in large part by the inefficiency of the process. However, it has caused a reduction in the profit margin and an increase in competition. Moreover, so long as this continues through the project paradigm an innovative new state will struggle to emerge, again because our level of thinking is too low.

We have built complex technology tools to use on traditional tasks, because we can. We have used these tools to generate more detail, more information and more data—because we can.

What we need to do is step back and look at the system within which we use these tools and raise our thinking to the architectural level. We must explore the opportunity to re-engineer our industry. To do this, we need to confront the shortcomings in our industry, our historic approach, and recognise that technology is only part of the solution. We must become more attuned to the needs of society. The future for the infrastructure engineering industry will be driven by the opportunity to create more value for society with the funds available. This will be a rewarding end for the transition of the industry.

And although the future is hard to predict, there are some trends that are apparent and in my view these will converge to build our industry anew.

Overall, the disruptive wave that is sweeping across our industry will take us from an essentially "planned" world to a new "dynamic" world. I have grouped the themes of change as follows.

/ **New operating model**

We will shift from a structured, standardized and linear approach based on empirical thinking to a world, which is unstructured, networked, continually optimised—manufacturing style.

/ **Philosophy and culture**

We will reverse the order of our thinking. We will consider whole of lifecycles first and their value. We will be driven by an outcome led approach. We will increasingly see single digital assets through their whole of lifecycle as the standard of how we do things. Our culture will become more thoughtful and purposeful. We will increasingly see design thinking as the template we use for our approach. This will lead the way. Increasingly our industry will build contracts of trust between members in the ecosystem. Our engagement methods will become more open and relationships will increasingly be seen as a win-win for all participants and stakeholders.

/ **Industry approach**

We will move from a single purpose or project centric approach and more toward a converged supply ecosystem that is inherently more efficient. Partnerships and cultural fit between organisations will become key determinants of success.

/ **Technology and working roadmap**

The technology roadmap will evolve over time supported by the inexorable reduction in computing power, the rise of cognitive computing to augment human performance, the convergence of Information Technology (IT) and Operational Technology (OT) within the engineering domain and of course the sheer motivation provided by the allure of wealth from the numerous available sources. Engineers historically have been very good at this part. However, the challenge in the "dynamic world" is that the technology developed will need to be considered at the system level. In other words, we will move from a series of point solutions to an integrated platform, a productised approach, designed to suit the particular whole of life needs of the industry and its assets.

The opportunity for the engineer in the future is to re-engineer our industry and ensure that this shift to a dynamic approach actually delivers the value and benefits to society that is its potential. But take note, it's likely this shift will happen with or without the input of the engineer. The current level of waste cannot continue. The question is who will lead—will it be the large consultancies and systems integrators, will it be the software companies, will it be the client or will it be the engineering industry that re-invents itself?

JAMIE LEACH

DATA TECHNOLOGIST, THINKER AND PRACTITIONER/ AUTHOR AND BUSINESS BUILDER/ ADVOCATE FOR THE TRANSFORMATIVE POTENTIAL OF DATA

> “DATA MAY BE THE REAL LIFE-BLOOD OF PROGRESS, FOR BOTH HUMANS AND MACHINES, BUT IT IS ALSO THE LIFE-BLOOD OF INDUSTRY 4.0.”

Data: the **life-blood** of *progress* in Industry 4.0

Jamie Leach

Data is the real life-blood of progress. After all, it affects every system, process and practice within today's organisations. As the engineering fraternity prepares for Industry 4.0, an organisation's ability to adopt appropriate processes and practices will be the difference between productivity and the probability of failure-to-thrive in the ever-changing work landscape. It's important for companies to ask themselves the right questions to examine their experiences and data maturity. Does your organisation collect or procure the necessary data to support an evolving strategy? Are you leveraging that data and the accompanying technology in the most effective way to meet your organisational needs? Are you adopting practices to reduce the senseless replication of data and to leverage existing data to augment processes and systems? If you found yourself asking questions such as these for the first time, you aren't alone.

Innovation through technologies and software has increased the ability for organisations to isolate and process data in the line of operations and management. The flux of data analytics and visualisation platforms has piqued interest in understanding trends ranging from production and financial through to staffing and marketing. However, one area of significant potential remains mostly untapped: the collection and processing of operations and manufacturing data that enables the introduction of predictive servicing and forward-thinking asset management practices.

Industry 4.0 will see production and plant managers in a myriad of sectors attempting to maintain aging assets and plants. The ability to create greater efficiency, reduce operational costs and to extend the lifecycle of machinery will all require an evolved approach to data. In addition to broadening the collection methods of various data sets, utilising the advent of the Internet of Things (IoT) sensors and linked Application Programming Interfaces (API), a cohesive strategy that will include artificial intelligence (AI) and predictive analytics (PA) may augment data analytics and visualisation platforms.

Leveraging data through AI may increase the ability to forecast the lifecycle of assets, or identify anomalous assets operations before the piece of equipment fails or the human operator has identified trends and behaviours. The ability to prevent downtime, or to circumvent safety breaches, has been made possible through data analytics and predictive forecasting based on a mixture of real-time data collection and historical data comparisons and statistical trend behavioural assessments. With increased data awareness, operators can identify and prioritise both capex and opex, including the adoption of innovations and solutions to maximise production, maintenance and resource allocation.

As the field of engineering progresses and becomes more dynamic, we will see the rise of domain experts distributing a mixture of technologies and tools, with AI algorithms and machine learning (ML) logics. While no two solutions will be exactly alike, the strategy and framework are replicable, leaving the number of sensors, or the customisation of the platform interface for the customer's operations before the solution can signed off upon. Implementation checklists, process manuals, FAQs, these are the elements that we can adopt from other's experiences, what is left, will enable the best working solution for each organisation.

One technology solution that is revolutionising, both internally-facing and externally-facing operations is Cognitive Services (CS). CS is the next generation of search engine that relies upon AI algorithms to search a pre-supplied database of results; providing the most appropriate response to the user in a more time-effective and reliable manner than traditional formats. Inside plant operations and maintenance environments, CS and cognitive intelligence may be paired with Intelligence Augmentation (IA) to support operational processes and decisional systems of staff and the logic of ML systems. Creating the searchable database requires a significant level of accuracy in the data inputted into the CS engine. Maintenance manuals, corporate records, trade-specific intellectual property, varieties of shared and open data and internal data forecasting are all examples of data inputs that can be leveraged in the creation of a CS engine as we focus on Industry 4.0.

By focusing on data within industry, increased efficiencies, safety and productivity can all be realised. However, the characteristics of the data, along with the quality, timeliness, utilisation and prioritisation of evolved practices, processes and ethics, will be the difference for those organisations and individuals that merge data and technology to the fullest. Data may be the real life-blood of progress, for both humans and machines, but it is also the life-blood of Industry 4.0.

Engineers leveraging the data value chain to **save our planet**

Simon Bryant

> I CAN THINK OF NO ONE BETTER TO 'SHIFT THE DIAL' IN SOLVING THESE CHALLENGES THAN AN ENGINEER ARMED WITH INDUSTRY 4.0 TECHNOLOGY AND MASSIVE DATA.

SIMON BRYANT

LEADER FOCUSED ON DIGITAL, DATA AND CO-INNOVATION/ PASSIONATE ABOUT LEVERAGING TECHNOLOGY AND DATA TO UNCOVER AND DELIVER INSIGHTS TO IMPROVE THE HUMAN EXPERIENCE

I wonder if the engineering profession has historically played a pivotal role in ensuring the sustainability of our planet. My long association with the profession has me answering resoundingly in the affirmative. I saw it first at university with a group of no-nonsense, solve-any-problem mechanical and civil engineering friends. They are now in influential leadership roles designing, building and operating critical infrastructure around the world. Secondly I saw it working closely with the analytical and systems thinking brilliance of engineers driving innovation for IT services businesses and their customers—a valuable by-product of the recruitment strategy of leading IT Services businesses which would insist on an engineering qualification as the preferred entry level requirement. The most recent association being a partnership with GHD, to bring to market an innovative combination of industry and technology capability to solve critical industry challenges in a sustainable way.

In my experience, it is the engineers' obsession with objectivity and data and systems thinking brilliance which brings significant value and has contributed to the historical legacy of the engineering profession. A combination of qualities which enables them to make sense of machines and structures and equips them to be designing, building and operating the assets that are the foundation of our planet.

If this unique mastery of data and the systems of things is in fact characteristic, then engineers have a new challenge and opportunity in front of them—discovering unmined value wealth for business and industry and solving big global challenges in an age of exponentially advancing technologies and troves of unexploited data. With the technology now available to us, we can collect data we have never been able to collect before. We can transport that data anywhere in the world at the speed of light. We can easily process and associate data from multiple sources to create massive data stores that provide new levels of meaning. We can provide analytical insights in real time to anyone who needs it and we can automate ecosystems with artificial intelligence (AI) to unlock un-tapped value by expediting new levels of systems interoperability. In our organisation, we call this the data value chain.

An inspirational example of the power and potential of the data value chain is the Copernicus Project. Billed as "Earth's Observation Program and Europe's eyes on earth", Copernicus is an unparalleled shared data platform built and operated by consortium of Airbus, the European Space Agency, Capgemini and Orange.

"Vast amounts of global data from satellites and from ground-based, airborne and seaborne measurement systems are being used to provide information to help service providers, public authorities and other international organisations improve the quality of life for the citizens of Europe. The information services provided are freely and openly accessible to its users." [1]

Can data and technology solve the grand challenges of our time? Absolutely! Copernicus shows the way with industry advancing, planet and humanity saving use cases which have been implemented on the platform: rainfall pattern detection and waterways health, crop and arable land monitoring, marine pollution monitoring, flood and fisheries control, validation of hydrodynamic models, resource exploration and land surveys—to name but a few!

The pace of technological development and data proliferation is creating profound changes for our lives and work. It is impacting all disciplines, economies and industries. What does this mean for the evolution of engineers in Industry 4.0? It means that a legacy of pivotal contribution is no guarantee of future relevance. For engineers to maintain and expand their relevance and contribution in the future, here are some guidelines to consider:

/ Avoid the technophile trap: engineers and their clients will be tempted by a fascinating array of new technology. Keeping a laser focus on value, and the associated business or industry or planet challenge to be solved, will enable the use of new technology in a way that returns value and is not merely an endless distraction on the road to nowhere.

/ Knowing the "art of the possible": understanding and leveraging exponentially advancing technologies—the vast array of new, budget friendly sensors and devices; the means to capture previously inaccessible field data and deposit it into massive data lakes; the tools to instantly and effortless make sense of data and persuasively visualise these insights in real time; the automation capabilities of AI—to name but a few.

/ Joining the Operational Technology (OT) and Internet of Things (IoT) dots: there is enormous value in integrating operational data (e.g. SCADA type data) from legacy asset systems with data from new IoT sensors and devices that can be easily and cost-effectively deployed and measure just about anything you can imagine! Engineers know the asset data, technology partners like we know the potential of IoT data—together they can be invincible!

Armed with these new, accumulated skills, what could a now digital-data powered, new-technology enabled Engineering 4.0 pay attention to? Well consider this—on Monday, 29 July 2019, 209 days into the calendar year, we had used up all the resources the earth could regenerate in 365 days (Global Footprint Network). Earth Overshoot Day—"the day when humanity overshoots the planet's ability to recover from what resources we consume within each year … At this rate, it would take 1.75 Earths to sustainably meet the current demands of humanity, according to the available data." [2]

Earth Overshoot Day has advanced by two months in the last 20 years.

Clearly this is one of, if not THE major challenge of our time. If you had any data you wanted and assumed that there are no technological barriers (there aren't) how would you solve this challenge? What would you pay attention to? How about ensuring the world does not run out of water by 2050?

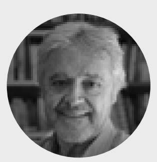
Considering the heritage and legacy engineers have in solving the significant challenges of our historical world, the Engineering 4.0 profession will be uniquely equipped to join the leaders of Industry 4.0 and significantly contribute to solving the water crisis and other complex challenges of our future. I can think of no one better to "shift the dial" in solving these challenges than an engineer armed with Industry 4.0 technology and massive data. All power to you!

[1] copernicus.eu website.

[2] World Economic Forum.

What is the **purpose** and state of engineering?

Larry Quick



LARRY QUICK

DISRUPTIVE STRATEGIST/ AUTHOR/ FACILITATOR/ ENABLER OF PEOPLE AND COMMUNITIES TO LEVERAGE DISRUPTION TO GENERATE SUSTAINABLE VALUE AND RESILIENT FUTURES

> "IS THERE A HIGHER ORDER OF THINKING THAT RAISES THE LEVEL OF PURPOSE FOR ENGINEERING IN THE CONTEXT OF THE DISRUPTIVE CHANGE WE FACE?"

Purpose, state and going MAD

What is the meaning and significance of purpose and state?

Simply put, a purpose is the reason for something to exist (to do something and in doing so add value). State is the context (or conditions) in which a purpose has meaning and survives, thrives and (hopefully) delivers sustainable value. Together this combination forms the basis in which all disciplines, businesses and industry sectors survive and thrive. Without alignment of state and purpose, immediate or eventual failure of anything is guaranteed.

In today's disrupted world, the dilemma is that the purpose of many organisations and sectors are out of sync with current and emerging conditions. And this dilemma is one of the key underpinnings of disruption. Many organisations and sectors are falling into a "failed state" through what we describe as MAD—Managed Adaptive Decline. MAD is a state where the conditions that once supported a purpose have diminished or disappeared and the organisation or sector is adapting to declining conditions, albeit in a well-managed manner. Like the metaphor of the frog that incrementally adapts to being put into cold water that gradually boils and eventually kills the frog, MAD is the first sign of any organisation or sector unable to or unwilling to understand, embrace and leverage change—especially disruptive change.

The understanding of this fact can be seen in examples of failing sectors such as banking and financial services, aged care, political systems, education, social services and our system of economic value generation. Their ability to embrace and leverage disruption to generate sustainable value is limited as they are weighed down by a legacy purpose that has fast diminished value in the immediate and emergent conditions.

So, the question for engineering as a discipline and sector and the organisations within it is:

What is the purpose of engineering in today's disrupted environment?

To assist in responding to this question, let's first dig deeper into what we mean by disruption.

Decoding disruption

Disruption is not new. Historically, it has been an essential part of life, the decline and growth of business and the evolution of the capabilities of people. From the first tools, to the use of fire and the wheel through to the agrarian, industrial and digital revolutions, disruption has always been intertwined with innovation to produce opportunity and advancement as well as uncertainty and unsettling change.

What makes disruption different today is the broad scope of change, its global scale, the exponential speed at which it is unfolding and the immediate, systemic impact on customer behaviour, channels to market, business and operating models, logistics, shareholder expectations and the underlying capabilities, skills and competencies on which all organisations rely.

For most organisations and their people, disruptive change is experienced as a rapid and disorienting break from what they are used to. As such, people and organisations find it hard to keep pace or even consider leveraging such changes. In this environment, our fundamental human capabilities, applied in the old way, are highly suboptimal. Conventional skills, basic competencies, ways of thinking, planning frameworks and approaches to strategy are not able to generate sustainable value and may even be dangerous.

Too often, people and organisations either lock into applying out-of-date capabilities by working longer, harder and faster or by applying change management, innovation, lean, agile or design thinking techniques that do not fully address the underlying issues associated with the challenge of rapid disruptive change. As a result, these approaches often fail to have the anticipated impact, become unfulfilled or meaningless investments, and can instigate a negative reaction to urgent responses to change.

What this means for organisations and leaders

For organisations an inappropriate reaction to disruption can lead to strategies that have little hope of working, the high costs of continuous reorganisation, unrelenting turnover of talent, workforces that are cynical about change and change plans, loss of productivity, compromised sustainable ROI and vast increases in material strategic risk.

It is in this state that organisational leaders are trying to answer the question, "What authentic changes do we have to make to our organisation to a) equip ourselves with the capability to meet and leverage imminent disruptive change, and b) what strategy do we need to leverage such disruption rather than fall foul of its consequences?".

Like every other discipline, sector and organisation, engineering must answer these questions.

What is the future of engineering?

A Google search of "what does an engineer do" reveals very interesting thinking:

"To engineer literally means 'to make things happen'. Most of what engineers do on a daily basis can fall into four categories: communicating, problem solving, analysing, and planning. Depending on an engineer's industry and role, their day will typically consist of a various mix of these functions".

According to www.careerexplorer.com/careers/engineer:

"An engineer uses science, technology and math to solve problems. We can see engineering everywhere in the world around us, improving the ways we work, travel, communicate, stay healthy, and entertain.

Today, the field of engineering offers more career choices than any other discipline. In the past, there were four major engineering branches: mechanical, chemical, civil and electrical.

Today, the number of available engineering degrees have greatly increased. There are now six major branches of engineering: mechanical, chemical, civil, electrical, management, and geotechnical, and under each branch there are hundreds of different subcategories".

On first view, these descriptions of the role of engineering and the value it creates appears to fit with today's state or conditions facing the world. But is that the right way to really gather and focus an engineering mindset, skill-set and strategic focus? Is this description the best use of an engineer in today's world?

Is there a higher order of thinking that raises the level of purpose for engineering in the context of the disruptive change we face?

Is a purpose that applies the engineering mindset, skill-set and strategic focus that leverages disruption and generates sustainable value in a way that directly addresses the social, economic and environmental disruptions we face with all of their potential for crisis, risk and opportunity a more compelling view?

What is the responsible and real future of engineering?

RICHARD SIMPSON

GEOSPATIAL AND BIM LEADER/ RESEARCHER/ AUTHOR/ CEO/ ADVOCATE FOR PROMOTION OF SCIENCE, TECHNOLOGY AND INNOVATION TO SUPPORT A RESILIENT "DIGITAL EARTH"

Engineering our **super sense** for innovation and survival

Richard Simpson

We perceive the world through our natural senses. These evolved to make us aware of our environment and have been essential for our survival. As we enter the Anthropocene epoch these natural senses will need augmentation by engineers if humanity is to survive. Like our natural senses this engineered "super sense" increases our cognitive awareness of the world around us and informs our decision making by revealing the marvellous complexity about the built, natural and social places we live and care about.

A Digital Earth represents the ultimate vision for a Digital Twin as it couples our planet's thermodynamic properties with associated environmental, economic, and other social phenomena. It becomes the common canvas for digital engineering of the Digital Twins. A Digital Earth will solve problems and build our collective human consciousness. It will highlight significant ethical, legal, social and unprecedented technical challenges.

Digital Twins must continuously learn and self-heal from multiple sources to sustain the pairing between the physical and digital expressions of the world. For example, Connected and Autonomous Vehicles (CAV) high definition multidimensional spatial and behavioral twinning will ensure the highest safety needs can be met. These methods are also beginning to be applied in major infrastructure and utilities projects, and progressive asset management applications. For example, Melbourne's South East Water has piloted a Digital Twin approach to reduce risks of sewer spill contamination of beaches. Real-time cyber-physical modelling of tides, weather, terrain, 3D pipe network topologies, pumps and hydraulic flows enable engineers to automatically monitor and predictively reconfigure pipe network and pump configurations to optimally respond to overflow scenarios.

Throughout history the engineering profession has weathered paradigms punctuated by new technology innovation. The invention of the steam engine, electricity, transportation networks, electronic devices have each induced deep societal, environmental and economic impacts. This emerging paradigm defined by Digital Twinning is referred to as Industry 4.0.

All disciplines of engineering will increasingly focus on the creation and maintenance of these cyber-physical systems. Digital Twins will scale and granulate as complex adaptive systems and eventually cluster as components within the emerging Digital Earth. Future engineers will need technical skills, cross-discipline thinking and fluency in an ever-evolving language to articulate such phenomena.

Sustaining cyber-physical relationships demands continued investment to ensure currency and integrity are kept. In addition to the twinning of physical attributes, digital-physical rights and obligations can be represented within a regulatory twin framework. Carrot and stick incentives for this investment can be framed as a regulatory twin. These are derived from demand side rather than more traditional supply side management of the assets. Such regulatory twins are being introduced with the 3D Cadastre piloting at Fishermans Bend in Melbourne, and environmental performance controls (sunlight, micro-climate, view protection etc.) in cities such as Singapore and Auckland.

Another way to incentivise is through the establishment of a commodity based monetary system in which value is encapsulated within a Digital Twin (similar to Carbon, Gold, Silver). This implicit value of a Digital Twin could be a measure of its representational integrity. This "truth" would be derived from the veracity, data provenance and other measures representational of the asset states. The Digital Twin then becomes a form of currency which can be awarded and traded with. The future Digital Engineer will be well versed in micro-financing and fin-tech economics to leverage longevity and the best investment returns from engineered cyber-physical creations.

Industry 4.0 will create unprecedented disruption into the business as usual for all organisations including utilities. Utilities will find it effective to separate the digital and physical operations of the business. The creation and curation of the Digital Twin would be owned by a separate entity—a meta-utility. The meta-utility is in essence a utility-as-a-service and will be better placed to attract the specialist talent and address growing cybersecurity demands and apply data sciences to optimize asset performance.

It becomes the new "smart" frontier for digitally interfacing with the home. Its business model would not be bounded by past convention and may converge all utility services electric, gas, water and even mobility. This seamless digital integration would leverage economies of scale and enable more effective co-location management of services while also motivate the pairing of complementary services, for example sewer gas for power generation. A meta-utility could be thought of as an API to utilities enabling agile and innovative value building. This will serve as an important modular building block for digital cities of the future. These digital metropolises are nested within the integrated built, natural and social environments twinned within a Digital Earth framework. We are already seeing a similar trend emerge in banking with Open Banking.

A Digital Earth will become the definitive engineering and scientific achievement of the 21st century.

Innovation is a necessity to survive in today's competitive business environments and to effectively meet the societal and environmental challenges imposed by climate change, globalisation, and urbanisation. To engineer is to innovate, and engineering organisations of all types and sizes must seek better ways to collaborate to out-think and out-innovate to meet the challenges and advance design and livability of places.

"A DIGITAL EARTH WILL BECOME THE DEFINITIVE ENGINEERING AND SCIENTIFIC ACHIEVEMENT OF THE 21ST CENTURY."

Six things Australia needs to progress innovation in Industry 4.0

Aleksander Subic

ALEKSANDER SUBIC

UNIVERSITY LEADER/ ENGINEER/ RESEARCH AND INNOVATION/ PRIME MINISTER'S INDUSTRY 4.0 TASKFORCE/DIGITAL TRANSFORMATION ADVOCATE

> "WE IGNORE INDUSTRIAL ADVANCES AND RADICAL NEW BUSINESS MODELS AT OUR PERIL. THE WORLD WILL CARRY ON WITHOUT US."

When Mike Cannon-Brookes, co-founder of Australia's most successful tech company, Atlassian, talks about Australia's potential in tech innovation, he compares it to our film industry. We won't beat Silicon Valley, the billionaire says, but just as our filmmakers, actors and cinematographers are among the best in Hollywood, we can stand as equals at the cutting edge of the world's digital economy.

But are we rising to the challenge in Australia or has economic sclerosis actually set in? You could be forgiven for thinking all the signs are pointing in the wrong direction.

Australian expenditure on research and development has fallen below 2% of GDP. The OECD average is around 2.4%, while Germany spends 3% of its GDP on research and development.

Australia has a high performing creative culture—and we are currently embarking on a major industrial transformation known as Industry 4.0.

Our competitiveness, however, depends on paying close attention to a number of critical factors. Some we're working on; others need a lot more encouragement.

These are my top six, in no particular order, to help make Australia the envy of the world. I am sure there are more—and each of these is interconnected and divisible into many sub-factors—but here's a good start.

/ Connected tissue between Australia and global innovation ecosystems

It has become commonplace to say we live in extraordinary times. That doesn't make it any less true. Industry 4.0 refers to the transformation in industry towards new generation technology (including robotics, 3D printing, artificial intelligence) interconnected via Internet of Things (IoT), and the development of new business models to support these.

To understand the full extent and ramifications of these developments, our researchers and companies must be embedded in global technology innovation ecosystems. At Swinburne University we are building deep partnerships with US, German and Indian institutions. This is about immersion, about enabling our researchers to transform industries in profound ways. Recently we partnered with CSIRO in the most mature innovation ecosystem in the world, Silicon Valley—the first Australian university to do so.

/ Industry and research co-creating

Co-creation is a business strategy that gives our companies a tilt at scale. I say this a lot, but it is worth repeating: A huge transformation is required this decade to build Australia's advanced capabilities—and a new model based on co-creation is essential if we are to achieve the hoped-for social and economic impacts.

According to the Global Competitiveness Index, Australia features high in research quality (12th out of 138), but moderate in innovation capacity (22nd) and in research transfer to industry (33rd).

I recently led the formation of the multimillion dollar national network of Industry 4.0 Testlabs, which will speed up collaboration and co-creation between educational institutions and industry in Australia, particularly small and medium enterprises.

This Testlab initiative is a national platform that serves as a catalyst for engagement, learning and change, and is a vanguard for future university and industry partnerships. We will soon have an integrated network of Industry 4.0 pilot plants located at six leading Australian institutions—Swinburne University, University of Western Australia (UWA), University of Queensland (UQ), University of South Australia (UoSA), University of Technology Sydney (UTS) and University of Tasmania (UTas)—each of them fostering industrial innovation and research transfer into the private sector.

/ Graduates equipped to succeed in an in exact future

Louis Pasteur famously said "chance favors the prepared mind." But how do you prepare for the unpredictable? I've studied the innovation literature, and no, you cannot legislate for creativity. What you can do is create environments and capabilities that will enable ideas to flourish.

Our students must rub shoulders with their counterparts in widely varying disciplines. Their diverse backgrounds and instincts must be celebrated, rather than moulded into something else. With these diverse perspectives, and by fostering collaboration that inspires and multiplies individual efforts, you can expect breakthroughs to occur.

/ The environment is fertile, adaptive and open

A vast amount of study has shown that diverse teams make the extraordinary out of the ordinary. But coming up with an idea is one thing. After they develop the breakthrough idea, the team must also be able to execute it. The research is clear on this too: diverse and inclusive teams—cutting across functions, sectors and identity—are also more successful in execution. And open access is critical.

The Industry 4.0 Testlabs follow key principles including open access to non-competitive collaborative learning environments for industry. Testlabs in Australia will collectively showcase shared experiences and produce joint use cases around Industry 4.0. They will also share use cases and outcomes with their counterparts in Germany and the US via our transnational agreements.

Innovation occurs at the intersection of all these places, virtual and real, through international linkages and interdisciplinary cooperation.

/ Investment in human capital

According to a recent World Economic Forum report, businesses will need to recognise that investment in human capital is "an asset rather than a liability" if they are to succeed in the unfolding Industry 4.0. This is where life-long learning comes in, where companies are adaptive and agile.

Our businesses will be rewarded if they allow freedom for employees to create, encourage collaboration around ideas, and enable retraining and upskilling as an integral part of their work. SMEs clustering around the production lifecycle at a Testlab will discover how they and their teams can create new value from Industry 4.0.

/ Innovation with a conscious purpose

Innovation needs a conscious purpose: it must drive impact. It must solve problems.

Each of the Testlabs—all supported by Siemens digitalisation grants rolled out across the network—has a laser-like research and industrial focus. For example, Swinburne works on Industry 4.0 processes based on new generation advanced materials—a pilot plant specializing in 3D printing of composites and graphene. UWA's Testlab is a new generation LNG process pilot plant and focused on the resources industry. UQ's focus is on building capabilities around intelligent distributed renewable energy systems; UoSA's Testlab specialises in digital shipyards. UTS is specialising in med tech production. UTas is focused on agricultural technologies.

Each has a purpose to drive national and global priorities for industry growth and for society's betterment.

Industry 4.0 is emerging as a unifying vision across Australia's diverse industry sectors, giving us a clearer focus and a roadmap for digital transformation of advanced manufacturing. We ignore industrial advances and radical new business models at our peril! The world will carry on without us. There are two futures out there for Australia: one at the cutting edge reaping the economic and social benefits from digitalisation and innovation and the other with our head in the sand. I know which I would prefer.

Through the **Looking Glass**

How might we, engineers and non-engineers, best use our skills, interests and ambitions to think outside the square and affect positive change?

Making a *difference* with **difference**

Jacqueline Linke

> **"In general art has preceded science. Men have executed great and curious, and beautiful works before they had a scientific insight into the principles on which the success of their labours was founded."**
>
> *William Whewell*

The term technology comes from two Greek words, "techne" and "logos". "Techne" meaning art, skill, craft and "logos" meaning word, the expression of thought. Thus, technology is transdisciplinary, but all too often we see the disciplines segmented into the science/mathematics fields or the arts/humanities fields.

The late Steve Jobs said "technology alone is not enough… It's technology married with liberal arts, married with the humanities, that yields us the results that make our heart sing".

What a time to be an engineer! Or an artist! Or both! Creativity used to be unspoken in business. Today, it is coveted as a way of mobilising and fostering innovation. We are on the precipice of a new renaissance, an opportune time for creating the conditions to thrive and flourish. To ensure that technology serves us we need to leverage the arts, put the STEAM into STEM, incorporate humanity. At this time of exponential change, there are challenges for organisations to keep up and not just survive but thrive. The continual nature of changes can be exhausting and people tend to reject the unknown. Fear and change fatigue are key risks for organisations and individuals in 2020 and beyond.

This is why innovation offers a protective component. It actually mitigates risk, makes us look more broadly at the canvas before us. It is also irresistibly exciting. Think of the potential of artificial intelligence (AI), automation, the Internet of Things (IoT), connected infrastructure, and Smart Cities. As soon as we master the new version of our smart phone, it is ruthlessly replaced by something moving ever closer to a personal robot, removing drudgery, making life simpler and easier.

JACQUELINE LINKE

CROSS SECTOR EXPERIENCED FACILITATOR/ WRITER/ LEADER APPLYING ARTS, CULTURAL AND INNOVATION LENS TO STRENGTHEN ORGANISATIONAL CULTURE AND TRANSFORMATION

> "AS GLOBAL CITIZENS OUR GREATEST OPPORTUNITIES LIE IN THE COLLECTIVE; IN LEVERAGING DIVERSITY AND SHARING AND WORKING COLLABORATIVELY, ORGANISATIONALLY, AND GLOBALLY."

Engineering has existed from ancient times, (though wasn't always called that), from when mankind first invented the wheel linking innovation and technology. Similarly art was key in communication in its earliest form as cave paintings. Artists in the Middle Ages used science to mix paints and decipher designs; engineers used artists' designs as a basis for the greatest constructions; humanities involved the marriage between science and art. Surgeons were barbers. There was not this artificial separation on professional lines. If we focus solely on one discipline, we miss opportunities to benefit from a broader understanding of the whole. Research shows that more Nobel Prize winners have artistic hobbies, interests or arts related thinking skills, alongside their science prowess, and polymaths have historically created some of our most important discoveries—think Leonardo da Vinci and Galileo who were both scientists and artists, making breath-taking contributions across disciplines.

The 20th century has seen a fragmentation of disciplines stemming from the industrial revolution and one task jobs, separating out arts and science and a surge of technological progress sometimes with impacts on society flailing in the wake. The world depends on technology now and we turn to our engineers and leaders to help solve our problems. Einstein said "we can't solve our problems using the same thinking that created them". The thing is we have this capacity within us already, to engage our thinking in a holistic way, expanding our ability to both exploit our experience, expertise and learned knowledge, and overcome our learned constraints with creative and divergent interventions and explorations.

Engineering plays a vital and complex role in social progress and impact on society. If science can tell us how to create an atomic bomb, then humanities might tell us why maybe it's not a great idea to do so.

I have seen amazing shifts in individuals and organisations when their creativity is optimised. Creativity is not reserved for artists. It is a core skill and belongs to everyone and needs to be practised. John Lasseter, Chief Creative Officer of Walt Disney and Pixar writes on art, "The art challenges the technology, and the technology inspires the art", both are optimised with the other. Skills in divergent thinking allow us to dream up the impossible and skills in convergent thinking help us find the optimal way to make it happen.

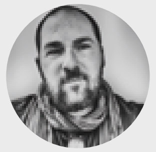
So how can we put ourselves on the front foot for the future and optimise our skills, expertise, knowledge, creativity and humanity? I think this starts with human potential; how we optimise our individual potential and our collective potential as teams and organisations.

One way is to mobilise our thinking, strengthening the brain power we use less often, creating a kind of cognitive collaboration internally, and another is to create collaborations of diversity externally. We can benefit from learning the skills to allow people and teams to pivot their contributions and value, to flex with the changing needs of an organisation. As global citizens our greatest opportunities lie in the collective; in leveraging diversity and sharing and working collaboratively, organisationally, and globally.

Whilst it isn't always immediately obvious to people that their thinking is limited, hours and hours of learned expertise means people remove options from their consideration. Transdisciplinary thinking trains our brains to make different associations, accessing disparate pieces of phenomena, linking seemingly unrelated ideas and making meaning, finding value in alternative perspectives, uncovering patterns, discovering new ways to see and do things. The human brain is not limited to one area of skill. We have this amazing computer available to us, our brain, and we can develop and sharpen the less used areas to open up broader horizons.

I think there is a wonderful opportunity highlighted by the advancement of technology for embracing the big picture, working together with different approaches which can only assist us in seeing more and understanding more. When mobile phones were invented no one anticipated they would cause car accidents. Perhaps wider thinking might have encompassed this and envisaged a solution. Wider thinking remembers the customer and what they want is important but does not stop there, because what the customer says they want is related to what they know now. Wider thinking looks at all aspects including the future.

Leadership, creativity and compassion will see engineers carving a path for social progress. The opportunity lies in optimising individual potential and organisational potential, embracing science and technology with creativity and collaboration; one of the most gratifying experiences humans can have—harnessing difference to make a difference.



ADAM JACOBY

DEMOCRACY WARRIOR/ SERIAL ENTREPRENEUR/ 2X CODEX WORLD'S TOP 50 INNOVATORS/ UNIVERSITY DIRECTOR/ WRITER

> "DID WE EVER IMAGINE DURING THE HEADY EARLY DAYS OF SOCIAL MEDIA THAT THE PLATFORMS WE WERE USING WOULD RESULT IN THE INCREASING DESTRUCTION OF DEMOCRACY?
>
> PROBABLY NOT."

Why engineers may become the **super heroes** of our time

Adam Jacoby

ENGINEER

noun

A person who designs, builds, or maintains engines, machines or public works.

I was recently in London to hear the Chief Scientist of NASA talk about a multi-national approach to mining exploration on the moon. The logistical complexity, innovation and solutions orientation required to achieve this goal is staggering. For non-technical folk like me, it is almost incomprehensible. The realisation of disruptive potential has always been and will likely remain the marriage of vision and capability. Ideas are like stars in the sky; there are too many to count and many other people may be looking at the same one at the same time. In most cases one's capacity to ideate is light years from the achievement of actual creation, deployment and uptake.

Equally, technical expertise is fast becoming a common commodity, with educators churning out thousands of technical experts each year. In the 1990s it seemed you couldn't go three feet without bumping into someone studying to become a lawyer, a sign of an increasingly litigious society. Excitingly, the same can now be said for engineers, coders and computer scientists. Yet, there remains a worldwide shortage of this expertise, a shortage that if unaddressed has the potential to stifle innovation, economic development and social impact.

Technical and engineering expertise has never been in such demand. Technologies have become the highways of our future and as a result, data is the new oil that fuels our global economies. The world that many of us live in is unrecognisable from the one our grandparents grew up in and for the first time in human history, developing nations have an opportunity to leapfrog the legacy infrastructure of the so called "First World" through the adoption and integration of the new technology and innovation revolution.

But the velocity of our evolution has ushered in a technological conundrum. Never before has there been so much opportunity to realise global and social impact through new design and innovation. Yet, due to the speed and global reach that technology now provides us, there has also never been such a risk of negative unintended consequences from our innovations. It is this paradox that demands a broad conversation about the ethics of capability.

Scientists, engineers, designers, manufacturers and entrepreneurs need to accept the responsibility for being the catalysts of change. Just because we can, doesn't mean we should and just because we are able to solve for a problem over here, doesn't mean we haven't inadvertently created a new one over there. The question we must begin asking ourselves is whether our innovations are taking us closer to or further from the first principle requirements of a cohesive and well-functioning society. Advances in computational power, data analysis and machine learning (ML) have dramatically enhanced our capacity to model innumerable potential futures resulting from our innovations. By better understanding these potential pathways we can build more robust and socially aware products that solve for the challenges and opportunities we have identified without creating new ones that we have overlooked.

A commitment to first principle ecosystem design, offers engineers and the engineering profession a unique path to superhero community status. By probing into areas that entrepreneurs, industry and government are unwilling or unable to, engineers can become the safeguard of unintended consequence and move beyond a traditional "expertise for hire" business model. By embracing and then embedding strategic collaboration on long-term, non-technical, macro outputs, engineers will be liberated to address the elephants in the room head on and seek to understand impact beyond their traditional project parameters.

Did we ever imagine during the heady early days of social media that the platforms we were using would result in the increasing destruction of democracy? Probably not. Could we have scenario planned enough to build better safeguards in its early iterations to avoid where we are now? Absolutely.

Social scenario planning demands more than UX and CX considerations. It requires an analysis of the adjacent and peripheral ecosystems of our projects which will inform how to better design and construct our innovations. This transition will be difficult. It may require new training, new models of measurement and new processes and systems but this investment is miniscule compared to the social and economic benefits they will bring. I encourage all engineers and aspiring engineers to put on the cape and come to our rescue.

TRENT CLEWS-DE CASTELLA

CO-FOUNDER OF IMMERSIVE TECHNOLOGY COMPANY PHORIA/ AWARD-WINNING INNOVATOR FOCUSED ON EVOLVING TECHNOLOGY THAT TRANSFORMS THE HUMAN EXPERIENCE FOR GREATER WELLBEING AND POSITIVE SOCIAL IMPACT

Strengthening the **bond** between people and place

Trent Clews-de Castella

Imagine—a digital overlay of rich information on top of the physical world, a contextual interface that improves a user's ability to interact with their environment and more importantly better connect with the people within it.

Software engineering as we know it is set to change. Tomorrow's engineering innovations are going to extend our reality in new and more meaningful ways. Industry 4.0 will usher in a paradigm shift from engineering high-rise buildings with optimal space utilisation, towards engineering buildings for a higher purpose with greater interpersonal wellbeing in mind.

As we reimagine how engineering will change in the future, it is clear the physical world will continue to become increasingly digital. As a result, the built environment around us will extend beyond what we can perceive with the naked eye and reveal hidden layers of information that spring to life around us. As our landscape transforms itself, the question remains, how will we interact with information in this new world?

Firstly, smart buildings will become living organisms of connected sensors, devices and data sets. Routine operations and programmed machines will work tirelessly to bring the old world online and connect our heritage with modern civilisation. We envision this future as a cohesive landscape where our most robust technologies converge with our innate human capabilities; a future that is designed to enable deep connections between business, culture and the environment.

The catalyst for this change is already happening around us. Moore's Law has excelled beyond our wildest expectations as cross reality (XR), quantum computing, spatial data, and artificial intelligence (AI) move from science fiction toward a ubiquitous set of new tools readily available.

As an example, our world view is defined by a physical map of the geographic borders, infrastructure and landmarks often used as we navigate to new destinations and explore new experiences. The GPS has been one of the most instrumental technologies to help position and orient us within this physical world today. Tomorrow, our self-driving cars will use GPS alongside computer vision, AI, Simultaneous Localisation and Mapping (SLAM) and 5G to navigate this physical world.

Industry 4.0 is going to benefit from machine vision, where a fusion of invisible sensors in a small form factor will scan, index and understand the world through our smartphones (AR) and wearable smart glasses (MR). Computing capabilities will expand exponentially through edge-computing processing power boosted down to our visceral senses. Accessible via web-enabled devices, XR interfaces will act as a bridge to the digital real-world, helping connect users with location-based data. This tool improves user engagement and provides greater contextual awareness. As a benefit individuals can better connect with and understand the physical world, improving wellbeing and community-based values defined by region.

Engineers in the future will enjoy an enhanced ability to design, weaving creative algorithms parametrically into their work. Industry 4.0 will combine form and function at the push of a button as biomimetic buildings embrace organic principles and values as a means to respond to the increasing environmental pressure and ecological unrest.

In this future, computing as we know it has changed for good. Our platforms, internet browsers and consumer devices have transformed the way we experience our surroundings through new user interfaces that seamlessly blend the digital and physical in a hands-free, heads up display. Originally led by the early efforts of tech giants like Apple, Facebook, Alphabet (Google), Microsoft, PHORIA, Intel, Magic Leap, Amazon, Samsung and many others who actively worked towards new levels of user interactions built on the web 4.0 with the integration of spatial data-sets and wearable technologies.

With these new innovations, humanity will be able to unlock the power of contextual information empowering a spatial understanding that overlays new meaning onto the world around us. As we move away from the escapism and addiction derived from social media and gaming, the future of entertainment will be location-based. Users will be encouraged to explore their surroundings, connect with like-minded individuals and strengthen the connection between people and place.

> "WE ENVISION THIS FUTURE AS A COHESIVE LANDSCAPE WHERE OUR MOST ROBUST TECHNOLOGIES CONVERGE WITH OUR INNATE HUMAN CAPABILITIES."

Humanity *amplified*

Jacyl Shaw

JACYL SHAW

**NETWORK BUILDER/
BOUNDARY SPANNER/
FORMER LAWYER/
DIGITAL INNOVATION
AND STORYTELLING
ENTREPRENEUR**

“

WE NEED TO AMPLIFY THE HUMAN. THERE WILL BE NO RELEGATION NOR PLAYING SECOND FIDDLE TO ROBOTS OR MACHINES AND DIGITAL OTHER WORLDS.

”

The inaugural “World Engineering Day” on March 4, 2020 offers an occasion to reflect upon the many historical achievements of engineering led innovation. There was James Watt’s steam engine in the mid-1700s that transformed textile manufacturing and transportation. 19th century mathematician Ada Lovelace’s role as the world’s first computer programmer laid the foundations for the extraordinary technology we have available to us today. Henry Ford, born just a decade after Ada’s death, managed to create the assembly line method of mass production and moved a nation on wheels. Decades later, actress and inventor Hedy Lamar discovered frequency hopping that not only improved plane aerodynamics but also devised a methodology that directly influenced wireless communications (Wi-Fi). The list goes on. These stories of discovery and innovation peppered through history help show us the potential of what the engineers amongst us and those with engineering type traits can achieve at junctures in time with resources, vision, verve and tenacity—those qualities that frankly make us human.

Innovation is not new; it has always been a part of our DNA as humans, prevalent and a leading change agent in humanity’s evolution. What is particularly interesting is the role engineers have directly played across the three prior industrial revolutions. First, our economics systems were industrialised and urbanised; secondly such systems electrified and the third revolutionised via computers. Now, here we are poised at the dawn of Industry 4.0 with what has been described as the fusion and interconnectivity of the physical, biological and technology worlds. Indeed what a time to be human; a time to (re)engineer our place in this brave new world. In the words of World Economic Forum Chairman Klaus Schwab we are at “the brink of a technological revolution that will fundamentally alter the way we live, work and relate to one another, In its scale, scope and complexity the transformation will be unlike anything that human kind has experienced before”.

Past gold rushes brought prosperity to many and paved the way for engineers to do what they have always strived to do: make knowledge (new or old) work efficiently for the betterment of society. This new rush is led and shaped by data. From bites to bytes, from KB, GB to terra, peta and exa it is extraordinary to think that 90% of the data in the world was created in last two years alone! So data is the golden vein of Industry 4.0 which means that those who respond to this reality will influence the new narrative of what it means to be human within the data-driven fourth industrial age.

It is also of interest to reflect how our systems of knowledge are moving rapidly from an era of containment, of silos and distinct divides between disciplines to what MIT’s Professor Neri Oxman wonderfully encapsulates as the “era of entanglement”. Engineers are working together with doctors and analysts to create systems for our fellow citizens to see and hear with bionic ears and eyes. However this interdisciplinary fusion is not new. In the 1960s, at the famous Bell Labs (founded by Alexander Graham Bell, the man credited with inventing and patenting the first practical telephone), artist Lillian Schwartz collaborated with computer designers to develop animation techniques that birthed the special effects disciplines now used in Hollywood and gaming. Within this current Industry 4.0 entangled brew of knowledge we also find new ingredients, “AR, VR, IOT, AI and ML” that, when combined, make for a delicious “digital alphabet soup”! For me, this era of entanglement offers a golden ticket for our engineering minded friends (and frankly all of us). It enables us to use data and digital and all that is afforded through Industry 4.0 to create opportunities and tackle complex challenges together so that economic, social, cultural and equitable prosperity can be enjoyed by all, anchored by knowledge, networks and pioneering ventures.

So, heeding from past eras and innovations, how might engineers, in tandem with other disciplines, anchor the human story to this era of digital transformation, this era of entanglement?

I believe it starts by being exactly what we are and can be, “amplified humans”. We must focus on those core human skills (sometimes called soft or enterprise skills) and the very things that make us non-robotic. The World Economic Forum, The Foundation for Young Australians and LinkedIn among others provide a plethora of research papers and findings on the measured value of these attributes not only for securing good employment but to live purposeful lives. The challenge for engineers is often (ironically) through specialised education. In stereotyping these more human traits and skills, they are de-prioritised or deemed not core to their craft or a distraction; what missed opportunities we all suffer from this short-sightedness. Fortunately, academia is starting to rectify this through careful curriculum change, emphasis on better communication and sense making and, of course, engineers themselves willing to show and celebrate these important characteristics.

“One machine can do the work of fifty ordinary men (humans). No machine can do the work of one extraordinary man (human)”.

— Elbert Hubbard, Writer

History has proven that, whether it’s engineering feats by the Wright Brothers or Leonardo Da Vinci fusing his engineering talents with arts that the extraordinary happens when, and only when, humans amplify. Look no further than the self-portrait by Surrealist painter René Magritte. In it, he only paints a picture of himself painting a bird, but he uses an unhatched egg as his point of reference. Magritte paints more than what is right in front of him: he paints the possibility, the future that it could be. The name of his painting: Clairvoyance. This is his perception of the future. What might your future hold if you dare to paint it or indeed imagine it?

No matter what industry you work in or your particular job within your organisation, there are numerous opportunities to contribute to the larger story unfolding within our lives by amplifying the human skills we have and utilising the technology that the digital age affords us. Our engineers, already discipline brilliant deploying technical trust at scale, must not be shy about shining a light on their other attributes to bring their best to collaborating and tackling the challenges of our times that will not be solved by any discipline alone. We need to amplify the human. There will be no relegation nor playing second fiddle to robots or machines and digital other worlds.

So as we march into Industry 4.0, I will leave you with these final suggestions:

- Remain curious
- Make time for creativity
- Keep learning
- Let technology be your friend but not own your reality
- Know what it means to be human

As 2020 kicks in and we stop to celebrate our engineers on World Engineering Day, we all have a responsibility to take lessons from the past, respect them, acknowledge them and build upon them, as extraordinary, amplified humans must do.

MICHELLE MANNERING

TECH COMPANY FOUNDER/ HACKATHON QUEEN/ MULTI AWARD-WINNING ENTREPRENEUR NETWORKED ACROSS ESPORTS, TECH, SCIENCE AND START-UP COMMUNITIES

> "UNLESS ENGINEERS AND DESIGNERS CAN WORK TOGETHER WITH THE CYBER WORLD, THE ENGINEERING INDUSTRY WILL NOT ADVANCE AT THE SAME RATE AS SOFTWARE."

Technology is far more than digital, it's **physical**

Michelle Mannering

It's funny how many people across the world, no matter which country or industry they are in, often consider "technology" as simply computers and software. People ask "is your company a technology company?" In reality, nearly every company is a technology company. But what people don't realise is technology isn't just computers and software. Technology isn't just applications and websites, and new pieces of artificial intelligence (AI).

According to official dictionary definitions, technology is "the branch of knowledge that deals with the creation and use of technical means and their interrelation with life, society, and the environment". Technology draws on different subject areas such as industrial arts, engineering, applied science, and pure science. It is this application of knowledge for a practical purpose that is technology. Technology also refers to a "scientific or industrial process" which can also be viewed as invention, method, or innovation. So what does this really mean? It means anything that is new is considered "technology". Back in the 1st century, pens and paper were considered technology. It was a new way of collecting and storing knowledge rather than remembering it in ones' head. Now, technology is all around us. It's all the new stuff. And, unlike popular opinion, it doesn't just refer to the software surrounding us. It is processes—smelting, 3D printing, CNC milling. It is materials—carbon fibre, kevlar. These things have been developed to help make things better. Now that Industry 4.0 is here, there's a much bigger emphasis on combining these physical products, these physical systems and processes, with something more digital. This is where we see the rise of Internet of Things (IoT).

Industry 4.0 is bringing about a wave of automation, data sharing, cyber-physical systems, IoT, and AI. These elements are not simply seen in software systems and processes, but more and more in the physical realm. Digital AI is being integrated into robotics to allow people to move, to see, to be helped by humanoid type assistants. Cyber-physical systems are bringing new ways to doing engineering; about building, testing, and delivering materials. Engineering is constantly evolving as engineers use digital means to help build the future.

Two of my previous companies I've been involved in are using this technology. Currently we're designing and delivering the Raine Electric Scooter. Everything from the design, to prototype, testing, and delivering are done so by leveraging the technology available in this new era of engineering. Computer Aided Design (CAD) software is at the point where most design can be completed digitally. This enables us to easily and quickly produce digital models, reducing the time it used to take to complete a design. Instead of sketching a design on a notepad and then trying to build it via wood, clay or similar—like engineers had to do in the past, we can take something from the notepad and put it into the computer. We can see the various layers of design, materials used, how those materials would act, and we can mathematically build it to perfection.

We can even model things on a physical level—engineers can use CAD to show how something moves under pressure, what parts are dependent on others and so forth. It doesn't eliminate the need to prototype entirely, it simply reduces design and prototype time.

For example, when we were building our electric scooter, everything was designed on paper first. You'll often still find James Murphy—the designer—sitting in a comfy chair with a hot cuppa and a notepad. Computers aren't there to replace that notepad. James's ideas today, and will forever, come out on paper first. CAD is a tool that he uses in the design process. From the notepad, all the drawings and designs are put into the computer. CAD then shows us how the design will mechanically work, how materials will act in certain situations, and allows us to calculate tolerances and many more mathematical pieces of information. Without CAD we'd have no way of knowing this information until we built a prototype—which would require a lot more time and money. Now we can go straight to building the prototype and work out the finer details.

The age of software has enabled us to build fully integrated digital systems into physical ones. Electric vehicles like the Tesla are essentially giant computers—they are driven by software and coding which makes the physical system work. This is the same with our electric scooter too. Electronics are just as much driven by code, as they are physically.

This is what the future of engineering will look like. Unless engineers and designers can work together with the cyber world, the engineering industry will not advance at the same rate as software.

It is critical our engineering and manufacturing continues to think outside the square, to consider how they can work better with digital technology to improve their physical technology. If we do this, then the future is bright. We need to move this to push the boundaries of technology and innovation. As the founder of Pixar, Ed Catmull says "making the process better, easier, and cheaper is an important aspiration, something we continually work on, but it isn't the goal. Making something great is the goal". So if we continue as humanity to innovate, to think outside the square, and to consider all possibilities, then we will inevitably make something great. That is the goal of Industry 4.0—to arm us all with the tools to make things better. Humans are amazing creatures. We can design, create, and build our way to a better future. We have an incredible pool of talent globally; all we need are the tools and resources to grow and foster that talent. Talent that will help solve worldwide problems, advance science, respond to crisis. That is Industry 4.0. It is providing us those resources and tools to build on our global combined human talent.

The road not taken: **reengineering society** with Indigenous knowledge

Cat Kutay

CAT KUTAY

RESEARCHER/ TEACHER/ ADVOCATE FOR NEW WAYS OF TEACHING, LEARNING AND ENGAGEMENT

The sharing of Indigenous engineering is deepening the understanding of sustainability and culture within the engineering discipline. To overcome past conflicts to grasp this opportunity, we acknowledge the rich history of technology in Australia (mining, water management, construction, management and systems thinking) and the present innovations coming from the Indigenous people only recently able to access the technical aspects of modern society. We value the challenges from such different perspectives as we navigate this cultural interface.[1]

Indigenous engineering has two aspects that are strongly coupled: the engagement of Indigenous people in the engineering discipline to provide work opportunity[2] and the development of engineering processes, technology and people to engage with Indigenous communities in a way that respects their different values and mindsets as clients, partners and teachers.[3] Many of our engineers will encounter such cultural issues early in their careers.[4]

These two aspects are linked as authentic consultation with community will train local people into the discipline and encourage engagement in future studies. Only by providing relevant study programs will Indigenous people see any purpose in engaging.

We can educate our engineers in what it means to design, develop and engage with community through[5] decolonisation of our institutions by revealing the hidden processes and assumptions that disadvantage Indigenous viewpoints and the decolonisation of engineering thinking so we can see and question our biases.[6]

The first step is to provide our students with the history of Australia and other Indigenous cultures since colonisation, so they understand the stories already shared within the Indigenous communities. This learning can cover the aspirations and priorities expressed by Indigenous people to have control of their land and resources and share an understanding of how this has led to a deep and intense feeling of belonging and relationship with this land.[7]

The next step is to evaluate the inconsistent treatment of Aboriginal engineers, technologists and people in general.[8] The juxtaposition of such differences can heighten empathy and awareness of how Indigenous people have struggled to retain their culture, their ceremonies and their lives.

Finally we consider how to change the perspectives of engineers through a deep understanding of the contribution Aboriginal and Torres Strait Islander people make to our culture and our creativity and engaging Indigenous people in engineering our projects. It was an Aboriginal pastor David Unaipon who achieved the title of the Australian Da Vinci. It was an Aboriginal woman Maria Locke who topped the exams in the early Australian school in Parramatta.

It was the Aboriginal people who greeted and provided for the early Europeans who came to Australia, who helped them traverse this country and then had to flee in fear of their lives. With 250 years since Captain Cook landed in Australia, we can now take the opportunity to learn what is left of the knowledge he failed to listen to through an inverted fear of the oldest culture on earth. In particular we can respect that the strong relationships within the Aboriginal community can provide engineers an avenue into the needs and aspirations of the local area where they might work.[9]

To provide a truly humanitarian approach to engineering we can use the processes developed by Indigenous people such as flat management for governance, team work based on strong relationships, yarning and deep listening.[10] However most importantly, the Indigenous depth of knowledge of country and the narrative processes used to both share and develop this knowledge are a crucial learning tool for engineers in the future to engage in sustainable development. Europeans have failed in this endeavour for thousands of years and this is now leading to the possible extinction of society as we know it. The complexity of managing an environment that is highly variable, with many interacting cycles, relies on the ability to retain a picture of the system as a whole while we work with the local parts in our respective projects.

To appreciate the Indigenous perspective on knowledge, the relationship to the land, and the language with which this knowledge is shared, Australians can look back on our Indigenous roots,[11] back to the time when we were on our own country, working with a deep understanding of the natural processes and the importance of all people. We all have the understanding embedded in our past, and in the stories we are told when young. Many know where our families came from back many generations, we keep that link as it is important to us. But most importantly we know which land they came from, and many of us travel back to see the land where their forebears lived, Indigenous and non-Indigenous alike.

Now we live on the land that belongs to the Aboriginal and Torres Strait Islander people. It is land we do not understand well, and this has led engineers, architects and agriculturists to make many mistakes. Indigenous people, despite all the anger and hurt, are still offering to share this country and their knowledge. We can take up this gift and offer in return recognition in our institutions of the Indigenous history of this land, and in the design of our technology with the growing population of Indigenous clientele and designers, to prevent exploitation and enable informed Indigenous involvement in practice.

> “TO PROVIDE A TRULY HUMANITARIAN APPROACH TO ENGINEERING WE CAN USE THE PROCESSES DEVELOPED BY INDIGENOUS PEOPLE SUCH AS FLAT MANAGEMENT FOR GOVERNANCE, TEAM WORK BASED ON STRONG RELATIONSHIPS, YARNING AND DEEP LISTENING.”

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Infomimicry–design the built environment with **"information as commodity"**

Gregory Millen

GREGORY MILLEN

FUTURIST/ INNOVATOR/ WRITER/ EXPERIENCE ACROSS INNOVATION, DESIGN, TECHNOLOGICAL AND ENTREPRENEURIAL ECOSYSTEMS

Two worlds of information

Today, we live and transact between two worlds, on one planet. All living and non-living things are composed of atoms.[1] Over millennia the evolution of atoms by "physical forces, chemical reactions and natural selection,"[2] has formed all within the biosphere including humans. These orders embody deep knowledge and know-how in "information *as* something."[3]

Circa 200,000 years ago humans kick started their consumption of the biosphere. Harnessing energy and tooling away brought forth our direct physical ordering of atoms to build things, founding our first inventions of "information as something". They too embodied deep knowledge and know-how, within the created technology and us. In contrast, our forming of marks (cave paintings), developed functions to communicate and store information outside ourselves in: "information *about* something."[4] These actions led to today's Information Communication Technology (ICT).

While busily building out of the physical (atoms) planet, we've built another. Fast-forward thousands of years, when ICT was plugged with the life-giving electric current, digitisation was born. Through our collective imagination and ordering of atoms, we have forged a digital world realised in bits (a series of the numbers 0 and 1), made from and for data, information and communication.

At pace over the last 30 years via the internet, we've pushed atoms into bits. Data fuels inventions only dreamed of a few years ago, such as artificial intelligence (AI). Now emerging technology is rising to push bits back out to atoms. But while digitisation provides huge beneficial change, its biosphere demand is ever increasing.

Globalisation's "interconnectedness of everything" and numerous other human megatrends require our attention. Today, our population is 7.7 billion and by 2050, we will hit 9.7 billion. We have become more urbanised than rural. By 2050 68% of the population will be urban. The digital world has connected 4.5 billion people and the Internet of Things (IoT)—sensory devices connected to physical "things", communicating data to the digital world, will go from 30+ billion this year to 75+ billion by 2025. The convergence of all and more brings us to an inflection point.

This adds new challenges to our existing ones at the intersection of the biosphere, with our economy and social lives. And nowhere are these challenges more evident and important than in the Architecture, Engineering and Construction (AEC) industries. Construction is the embodiment of the physical world. Yet the opportunity for transformation via working through both physical and digital worlds is extraordinary.

"Shelter from the storm"

Everyone and everything within the biosphere, including machines, need shelter—a basic "form" and "function" foundational requirement for humanity and all.[5]

The property lifecycle—land, build and asset, is intrinsically finance intersected. Real estate (land and asset) holds 70% of the world's wealth.[6] This year 2020, the build (design and construction) global spend forecast is above US$10 trillion and rapidly rising.[7] However, construction globally is second only to agriculture and hunting in its lack of digitisation.[8] In my co-creative industry research and development, I have highlighted the key problem of "missing information" i.e. this sector is struggling to take advantage of both worlds.

Though in infancy, Building Information Modelling (BIM) as a transformational solution is moving front and center. BIM via digital integration is a new way of working, including such innovations as point cloud scanning, IoT, cloud computing and lean methods. Instead of producing 2D drawing outputs about what is to be built and translating via one's mind's eye how it will look in its finished form and function, BIM's iterative 3D modelling methodology produces a virtual digital replication of pre build/modification, in an as built state—a mirror as if a completed physical world build. This is otherwise commonly referred to as a "digital twin" prototype.

The replica made is the composite of every individual building component/object, the sum of all the parts. Used by multiple stakeholders, while simultaneously worked on, replication is both single-view presentation, and allows the composite whole build to be deconstructed and broken-down to single object views of transparent layers. It is instantaneously clone-able, during integrated work in progress, on jobsite and in office.

Replication is forensically driven to identify problems and provide solution diagnostics. It increases productivity by the push/pull of building objects into other builds and/or supply-chains i.e. model to manufacture to on-site assembly. Achieved by unifying massive sequences of data disconnects and disparate levels of technology adoption across a vast, diverse and fragmented set of stakeholders, BIM's impact is driving up to 65% reduction in disputes, 40% faster build and 90% less waste.[9]

Infomimicry, merging worlds

I see BIM's replication revolution at its core to be the transformation of elements of information about something (drawings) into information as something (model).

Furthermore, what is truly remarkable by this information transition, is the bringing together of information, along with data capture or transmitter capability, into a single "combined state" replication object and file. I foresee this combined state of embodied knowledge and know-how to have yet-to-be-seen positive disruptive qualities, deep meaning provisioning and exponential data utilisation.

As digital is infinite, imagine a single combined object likened to an individual container. Any data or information type for any industry can be placed in the object. Its flows open up a myriad of uses. For example, you can track when, who did what, and how, 3D printing, jigsaw qualities, provenance identifiers, and push/pull to commodities markets, insurance, asset management, energy, smart city, and so on.

Looking beyond, as the digital world allows one to see the unseen physical world, all within the entire biosphere can benefit. Replication has total resource mapping and measurement potentials, from every grain of sand (to make a brick) to throughout the property lifecycle and across the built environment. From the ordering of atoms to create new materials to designing an intelligent regenerative asset, in itself in both atoms and bits, while looping back to physical and digital. This means an asset can respond, interact and transact with occupant and other intelligent assets, between both worlds, on one planet.

The physical and digital worlds combined are our total infosphere, in which we live, powered and sustained by the biosphere. The same amounts of atoms are available today, as yesterday, as there will be tomorrow. From here on in, it's what we choose to do and how we are with them that's going to count.

Moving through time, space and commerce—ultimately this interplay and transaction between atoms and bits—the crossover and merging creates a third space, the occurrence of information mimicry, which I term "Infomimicry". All this leads to multidimensional industry and technology convergence, delivering new forms of supply and demand, and new value creation with what I phrase to be "information as commodity" in the digital world. As we evolve to the future, there is positivity to look beyond the human centered models of today, to design and engineer a new orientation based on a harmonious balance between people, the technology we create and the biosphere.

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Future Voices

How might we, budding engineers, inspire others and demonstrate the mindset and skills our future needs?

Grace Tudreu

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Ana Taylor

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P-Cubed

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Jenine Beekhuyzen

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JENINE BEEKHUYZEN

TEACHER/ AUTHOR/ AWARD-WINNING FOUNDER/ ADVOCATE OF TECHNOLOGY, INNOVATION AND DIVERSITY IN STEM/ TECH GIRLS ARE SUPERHEROS

Tech Girls are **Superheroes:** The *P-Cubed Journey*

Jenine Beekhuyzen

Meet Halle, Deepika and Chloe—ten and eleven year old's finishing year six at a Brisbane school. Two years ago I did not know these girls, and now I cannot imagine my life without them. Together they make up the P-Cubed team—Plastic Pollution Preventers.

Two years ago, one of the girls' mothers suggested that she participate in the annual Search for the Next Tech Girl Superhero competition, a 12-week Australia-wide STEM entrepreneurship program where teams of girls build apps to solve local community problems. The mother suggested this as her older daughter had competed previously, and enjoyed it. But the younger girl said "No. I don't want to do it because I won't be any good at it". She opted herself out before she even began her STEM journey. But luckily her mother was persistent and suggested more strongly that she find some friends and enter the competition, which she did.

The team of girls, Halle, Deepika and Chloe, not only competed in the 2018 competition, they developed an extensive business plan, public pitch and working app (available on the Google Play store), and they won the Australian Nationals! As Australian Winners of the Primary School category beating out 500+ other girls, the team used their app to encourage us to reduce our single-use plastic use, advocate for the environment and pollution reduction, and create partnerships with other like-minded eco organisations. They also created a movement in their school called "wrapper-free Wednesday" for lunchboxes, were featured on TV reaching a national audience, and have presented to politicians, and to rooms of more than 500 corporates at conferences and gala dinners, without breaking a sweat!

With seemingly endless energy, many new ideas, and the biggest smiles possible, these girls are now the cool girls in school. Others in the school high five them as they walk past, congratulate them on their latest accolade, with many younger students emulating them. There is a new young team prepping to enter the competition next year in year four at their school, and they have already begun working on their app six months before we launch the 2020 competition in March. And they call themselves "Little Halle, Little Deepika, and Little Chloe". A true tribute to our P-Cubed team.

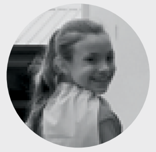
What does this tell us? Firstly, we need to invite people, particularly girls and women, to participate in STEM. Recent research out of the US found that 80% of women studying Computer Science in one particular faculty, did so because "they were invited". Opposed to the men studying who were doing it mostly because "they enjoyed it". This is profound. The example you just read above is this "invitation" in action, firstly by the daughter, and then to her friends to join her. *Why not consider* who could you invite to [be at the table], [nominate for an award], [put forward their ideas in a meeting]?

It also tells us that we need purposeful STEM to engage young people. We need young people to be solving not only problems but young people's problems and issues that they care about. How refreshing it can be to have a young person's perspective on age old problems like climate change and pollution. We've seen that with Greta Thunberg on a global stage. Of course this problem isn't only theirs, but they recognise it, and are willing to own it, and work on fixing it. Their tenacity and dedication is inspiring.

This story also tells us that community is important. It really does take a village to support young people engaging in STEM. Engaging in STEM is not a one-off and it doesn't require lots of resources. But it does help to have some great resources in your toolkit like mentors—all of our teams of girls are matched with a female STEM mentor—and a productive environment to encourage collaborative work. Usually learning the softer skills as they are often called, skills like contributing to team meetings, scheduling, planning, prioritising, are more difficult to learn than the technical skills. Many of our girls learn to code by themselves via YouTube!

Not only have our P-Cubed girls been local heroes for the last year, they also pitched their apps and ideas in Silicon Valley in August 2019. As part of their prize for winning the competition, they spent a week pitching to execs and engineers at Google, eBay, Facebook and NASA to name a few, and they wowed local venture capitalists and CEOs alike. They wowed New York Times best selling author James Clear and many of our Uber drivers by singing their song that was designed to explain their app with a chorus and dance! I even spotted them dropping business cards on people's desks as we walked through the offices of some of the companies. Along with two other teams of girls, the P-Cubed team were incredible ambassadors for Australia on the trip, making us so very proud of them. These girls are not leaders of the future, they are leaders of now.

"THESE GIRLS ARE NOT LEADERS OF THE FUTURE, THEY ARE LEADERS OF NOW."



P-CUBED

THREE PRIMARY SCHOOL FRIENDS COMMITTED TO SAVING THE WORLD FROM PLASTIC POLLUTION/ MULTI AWARD-WINNING RECOGNITION/ TECH GIRLS ARE SUPERHEROS

What we need for the **future of engineering** to be bright

P-Cubed

> “ENGINEERS NEED TO BE ABLE TO SEE THINGS FROM DIFFERENT PERSPECTIVES SO THEY NEED EMPATHY.”

New technologies are amazing! Each year sees more innovative inventions and upgrades to our existing devices, such as brand new computers and new phones due to people's desire to stay connected. But, today, we live in a throwaway society. People throw away their old phone, that may only be one or two years old, in order to have the latest model. But, have you ever stopped and thought about what happens to it and the environmental impacts new technologies create?

We are P-Cubed, a team of three girls aged between ten and eleven, and we are passionate about our environment. We have many ideas about technology and engineering and how what we do now and in the future will shape the world in which we live. In 2018, we won a national technology competition for our app, Plastic Pollution Preventers, and this launched us into an amazing experience that has opened our eyes to the promises that engineering makes for our future. It has also made us think even more about the kinds of people that we know we need in industries to make sure that the future is the kind of future we all want and need.

One of the things we have learnt through our journey with technology over the past 18 months is how important it is to know our own values and to work with others who have good values that are aligned with ours so we can make a positive difference in the world. Our app and our philosophy aligns with the United Nations Sustainable Development Goal (SDG) #12, which is responsible consumption and production. We have been lucky to have made great partnerships with organisations such as Tech Girls Movement and Tangalooma EcoMarines. Through these relationships we have had great mentors and been inspired to learn more about how technology can make a difference to our world.

In August 2019, we travelled to Silicon Valley to pitch our app to tech giants like Google and Facebook. We met many inspiring women who talked about how their work in technology and engineering allows them to make a positive impact on others' problems.

Society's love of new technologies means that we throw away many devices and this raises many environmental concerns about air pollution, soil pollution and water pollution. There is also an important ethical concern about information security and data privacy. All of these issues need to be considered prior to the design of new technologies or we will be left with unusable soil and water supplies and increased health problems worldwide that will cost more money to resolve. There are approximately 7.7 billion people in the world and if all of these people consume goods without thinking about the consequences, this will be disastrous for our planet. The world already produces an alarming 20-50 million tonnes of e-waste annually!

We think that it is vital that the engineers designing these devices have strong ethics and can be creative in order to minimise the environmental impacts of new technologies. Engineers can lead the way by making it easier to repair or upgrade existing technologies so that they last longer. Creative thinking leads to good design that makes it easier to take apart electronic devices in order to encourage recycling parts so that toxins such as lead, mercury and chromium from e-waste do not contribute to landfill or contaminate soil and water supplies and reduce the harmful health effects.

As well as creativity and ethics, engineers need to have empathy. Not everyone in the world has the same access to technology and if we are not thoughtful, we will make this problem worse, not better. Engineers who are empathetic can make affordable new technologies and the social divide throughout the world could be minimised. This would ensure a positive future for everyone worldwide!

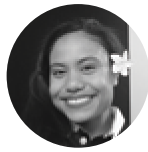
Technology has the potential to make a positive impact in the lives of many people who might not have equal opportunities otherwise. Engineers have an important role in designing tools that help to make people's lives easier, especially elderly people and people with disabilities. By understanding exactly what a person with a disability requires, this can make an enormous difference to someone's life and make them feel included. Engineers can help design and create products, buildings and transport that meets specific needs.

Engineers have already helped people with vision impairment with features like text-to-speech and face recognition so they don't have to type in a password, and making information available using audio. Engineers all around the world have designed and developed solutions for people with hearing impairments too. Some incredible innovations include hearing aids and Tele text/ subtitles. Using FaceTime can allow people who communicate with sign language to make phone calls. Inventions like prosthetic limbs, voice activated devices, and head tracking software make other technologies more accessible for people with physical impairments. Every day, engineers are designing and developing new products for people with disabilities and for the elderly.

Engineers need to be able to see things from different perspectives so they need empathy. This is why it is also very important that there is a good diversity in engineering. Women and men might see things differently. People from different backgrounds and cultures can bring different points of view and the different generations can bring new ideas so that solutions can be made for everyone.

We think the future is very exciting. Engineering promises us the chance to solve problems in other people's lives and to improve our world. We will live in a world where the fridge can order its own milk when it is running low and bots will make sure your room is clean and you can find everything you need, and we will have driverless cars and be better connected to the world, but this future could come at a big cost. We worry that many people will lose their jobs and that not everyone will have fair access to new technologies.

To create the future our world needs, we need engineers who can make decisions based on good ethics and values, we need engineers who can think creatively to solve problems and who can bring different perspectives and think empathetically. If we have engineers like this, our future will be very bright.



GRACE TUDREU

ENVIRONMENTAL ENGINEERING STUDENT/ ADVOCATE FOR ENVIRONMENTAL AND EDUCATION REFORM AND MINIMISING CLIMATE CHANGE IMPACTS ON PACIFIC ISLAND NATIONS

"THE FUTURE OF THE GLOBAL ENGINEERING INDUSTRY WILL ONLY BE AS STRONG AS ITS WEAKEST LINK, WHICH IS, IN MY OPINION, THE CURRENT SCARCITY OF EDUCATIONAL RESOURCES, EXPOSURE AND ENGINEERING INDUSTRY OPPORTUNITIES FOR YOUNG BOYS AND GIRLS IN DEVELOPING NATIONS."

Empowering Pacific Island nations through **STEM education**

Grace Tudreu

"Whatever you choose to do, you have the potential to help change the world with that creative and intelligent mind of yours." That was what my beautiful mother challenged me with, at the end of my final year in high school. She always has a way of eloquently and firmly encouraging you with her words, and putting things into perspective. The aftermath of that conversation led to me sitting in my bedroom, taking out my journal and writing out my goals and dreams. Despite how crazy these aspirations sounded at that time, I decided to dream big. With a clear vision before me, I slowly started working towards them.

I did not envision myself pursuing a future career in environmental engineering, but I am grateful that it has slowly become one of my passions and a journey of growth in all aspects. Fast-forward to 2020, here I am in a foreign country and in my final year of studies, with nearly four years of unique challenges, learning, failing and getting up again, and becoming inspired to be a catalyst for change.

Although I am hugely grateful for the diverse educational opportunities presented to me while studying in Australia, I constantly think about my brothers and sisters back home. Growing up in a developing island nation, it seemed easier to dream small than to dream big. There are limitations and obstacles due to the social and economic inadequacy. Growing up in Fiji, I have noted several key areas that require significant development and investment. These include, but are not limited to, climate change mitigation policy, access to quality education, water sanitation and hygiene, medical assistance, employment creation and town planning. Despite these reasons potentially being used as excuses for dreaming big, I personally believe that a person's background is not the sole determining factor for the success of their future. Focusing on education, a large number of public schools back home lack access to computers and opportunities to learn code, which places students behind others in developed nations. I am not disregarding the fact that we do regularly work to improve our education, but I am expressing that we can do better. We need to do better if we, as a small developing archipelago, want to survive Industry 4.0.

Engineering is not only gaining but also applying learned knowledge to solve global issues and improve the livelihood of everyone. Therefore, the future of the global engineering industry will only be as strong as its weakest link, which is, in my opinion, the current scarcity of educational resources, exposure and engineering industry opportunities for young boys and girls in developing nations.

I believe the richest asset and resource for Pacific Island nations are the students in our classrooms. Envision a world that is steered by innovative and intelligent engineering minds of various disciplines, represented in all countries. Now, take time to think how you as an individual, with your connections and expertise, can contribute to a promising future where the connection between the physical and digital world is practicable worldwide! There are three questions that I ask myself at the beginning of each academic year:

/ "What educational opportunities and resources here in Australia can we also introduce in a developing nation so that students get access to equal opportunities?"

/ "How can I apply what I learned in the classroom back home in my country?"

/ "How can I grow: not only in my career but character too?"

I challenge you to ask yourself these questions too and find practical ways to apply them. Dream big but start with small steps. They do not have to be engineering focused and can be related to any profession or passion of yours.

Two suggested mechanisms to improve engineering education in Pacific Island nations include: **(i) coding for the future:** introduce coding classes in both the primary and secondary school education curriculum. The beginning classes will be compulsory for all students; however, students then choose if they want to continue into intermediate to advanced levels. **(ii) STEM Rooms:** Introduce STEM rooms for after school programs. The program will involve students using their imagination and creative intelligence to find solutions to either a local or a global problem chosen by themselves, using locally available resources. In this way, we are encouraging students to be innovative at a young age, think outside the box and be active learners. By the time they reach university, they will be equipped and ready to tackle the same identified issues, but at a larger scale.

Presently, the education gap between developed and developing nations is large, however, with the right local and international support, we can minimise this gap. We can then be hopeful of a future where aspiring engineers worldwide have equal opportunities for education. We can be hopeful of an industry that is competent and ready to face the challenges of this digital era.

ANA TAYLOR

BIOMEDICAL ENGINEERING STUDENT/ ADVOCATE FOR EDUCATION REFORM AND A FUTURE WHERE TECHNOLOGY IMPROVES HEALTH AND QUALITY OF LIFE

Engineering tomorrow requires change to **education today**

Ana Taylor

Throughout my youth, my parents had always encouraged me to pursue a career in engineering. However, I always rejected this suggestion due to my stubborn unwillingness to do as I was told and the perception that engineering was all about maths (and therefore extremely boring). However, as I grew up, I have been introduced to the broader reaches of the industry and the many exciting disciplines that it offers. I realise it has the potential to be much more innovative than I once thought and now find myself studying in the field, much to the surprise of my younger self.

As a student in biomedical engineering, I am encouraged with many exciting avenues to pursue. As a much newer discipline and the knowledge that humans will always require healthcare, I do not feel the threat of digitisation limiting future job opportunities. However, I do believe all budding engineers must consider the concept of supply and demand. With an ever-increasing population and effect of globalisation, the competition pool is growing exponentially and thus the need to "set ourselves apart" is becoming increasingly important. But how do we do this? How do we as students build up a portfolio of experience to ready ourselves for the workforce when the idea that "it's not about what you know, but who you know", seems so evident? I believe universities have a major role to play in ensuring up and coming engineers have the opportunities while studying to develop key thinking skills through industry-led learning and must therefore fundamentally change their approach to teaching.

> "THE NATURE OF A CURRENT UNDERGRADUATE EDUCATION IS TO TEACH STUDENTS HOW TO SOLVE A QUESTION THAT ALREADY HAS AN ANSWER, RATHER THAN PROBLEM SOLVING BY COMING UP WITH THE ANSWERS THEMSELVES."

While studying, I have come to realise that tertiary "education" is a process as follows: listen, copy, memorise and copy again. There is little room for ideas and more frighteningly there is little emphasis on understanding. Students have cleverly figured out that you do not have to understand in order to pass, but rather *convince* assessors that you understand. Major flaws exist in how students are being assessed and with the popularity of the mantra "P's get degrees", students have lost the drive to push themselves and stand out. The nature of a current undergraduate education is to teach students how to solve a question that already has an answer, rather than problem solving by coming up with the answers themselves. While learning from the past is vital, students should also have the opportunity to learn through doing. It is important that universities and companies create more meaningful partnerships that provide opportunities for more students to collaborate with industry professionals and contribute to current projects. To put this in practice, companies could allow more students from a wider range of universities to be involved in industry research projects or create groups within companies, specifically designed for students to work on projects under the guidance of practising professionals. This type of project-based learning would create more excitement and passion and lead students to think more critically about future work opportunities.

Personally, I would find it very exciting if part of my education included working on an industry project to deliver a solution to an actual problem. Opportunities like these would be great for facilitating innovative mindsets, idea development and even confidence. Imagine if graduates entered the workforce, already having some useable, professional experience. This would fast-track their integration into a working team, improve collaborative and communicative skills and may even provide them with enough confidence to take on new challenges. If more engineers started out their careers with passion and readiness, not only would this be beneficial to the individuals but also for the industry itself, as it would have no problem providing innovative solutions to new problems for generations to come.

It would be a shame to see no change in the education system and for many engineers to graduate knowing how to answer questions but not knowing how to solve problems. This is where the challenge lies. If you ask any engineering student to use vector calculus to find the relative velocity of car A to car B, they will manage to do it, but ask them to solve a problem not yet answered and most of them will malfunction. This is a sad insight into the future of engineering if you ask me.

I believe that if universities and industry can collaborate to come up with new ways of teaching that also prepare engineers for innovative thinking and meaningful work, this will help ensure there is continuous growth in what is produced by all disciplines. Mostly, I hope my education prepares me to take on new challenges and one day create something that will improve the quality of life of others.

CONTRIBUTORS

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Adam is a serial innovator with 20 years of experience leading fast growing businesses in the sport, information and media industries. His successful start-ups include IMS Sports, LifeLounge.com and global Mummu group of companies with recognition by Anthill Cool Company 2013 Awards, #40 BRW Faster Starter 2015 and Top 10 in Smart Company's Smart50 Awards 2015. He was also CEO of BRW's 2010 Fastest Growing Private Company (under $100M), Sportsnet Co. and non-executiveChairman of ASX listed eSports Mogul Asia Pacific. Adam has presented at the 2017 and 2019 Codex World's Top 50 Innovators Conference, 2017 World Economic Forum, March for our Lives Rally and Stanford University and is founder of the global political movement MiVote.

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With extensive experience researching and working with public and private sectors, Adela is a professor and the College of Business Professor Mentor at RMIT University. Recipient of four Australian Research Council grants, two industry Collaborative Research Centre industry grants and other grants she has also published over 260 publications. Adela was chair of the US Academy of Management's International Theme Committee and serves as a member of numerous journal Editorial Advisory Boards. A recipient of many international best papers, teaching and leadership awards, Adela's research expertise addresses workplace innovation and organisational culture including climate.

PG 36

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Aleksander is a professor and Deputy Vice-Chancellor (Research and Enterprise) at Swinburne University of Technology. Key achievements over the course of his career have included international recognition for his research in engineering design and advanced manufacturing and leadership of global R&D projects in collaboration with industry. Aleksander has held a range of notable chair, director and member positions with various organisations, associations and councils including the Prime Minister's Industry 4.0 Taskforce and the Australian Advanced Manufacturing Council Leaders Group. He is a Fellow of the Institute of Engineers Australia, Fellow of the Society of Automotive Engineers and Fellow of the International Energy Federation.

PG 66

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Alexe is a technology inventor and business innovator, whose work has been utilised by organisations including IntAIB, iiRNet, IBM, the US Air Force and the Australian Defence Force. He holds eight US and international patents, has published numerous technical reports and papers and wrote #1 international bestseller *Innoaphorisms: a spark each day – EMPOWER INNOVATION*. With a PhD in data science, Alexe is a pioneer in deriving insights from big data. He has contributed to the development of the first bionic eye in the UK in 2003, the first IoT fault detection system in 2011 and the first aerial RADAR system made of carbon fibre.

PG 22

Ana Taylor

Ana is a university student completing an honors degree in biomedical engineering at RMIT. Her interest areas include tissue engineering, biomechanics and neural engineering. She hopes her future in engineering involves developing cutting-edge technology that improves health and quality of life for future generations. Ana represents her peers in student council activities and aims to use this platform to improve the quality of education for her fellow students and leave a lasting change for incoming students. Ana sees the future of engineering being centered on how engineers are shaped by education.

PG 92

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Anette is a professor in engineering education and director for the Aalborg Centre in Problem Based Learning in Engineering, Science and Sustainability under the auspices of UNESCO at Aalborg University in Denmark. During the last 20 years, she has undertaken research primarily within engineering and is the recipient of numerous awards including 2013 IFEES Global Award for Excellence in Engineering Education and 2015 SEFI Fellowship Award for "deserving service for engineering education in Europe". Anette is also associate editor for the Journal of Engineering Education.

PG 38

Dr. Anton Middleberg

Anton is the Deputy Vice-Chancellor and Vice President (Research) at the University of Adelaide. A former Fulbright Scholar, Anton has held numerous research and leadership roles at prestigious institutions including University of California, Berkeley, University of Queensland and Cambridge University. He is an internationally recognised research and thought leader in chemical and biomolecular engineering and has researched, patented and licensed new technologies in the fields of rapid vaccine scale-up, soft-condensed matter and bio-nanotechnology. His work has been recognised by the Fellowship of the Australian Academy of Technology and Engineering through awards including the Brodie and Shedden-Uhde Medals of the Institution of Engineers.

PG 42

Dr. Cat Kutay

Cat is a lecturer and researcher (computing and electrical engineering) at the University of Technology Sydney. She has been working in Sydney for over a decade developing software for teaching Aboriginal culture and languages and techniques for experiential learning of renewable engineering systems. Cat completed her PhD in support for online group learning using social constructivist pedagogy. Cat's research is in the area of computer-supported collaborative learning and draws upon concepts from traditional relationships and responsibilities. She also researches teaching content, approaches and optimal methods for course delivery online including gaming and multimedia feeds such as podcasts.

PG 80

Dr. Charles Day

Charles is the CEO of the Office of Innovation and Science Australia (OISA). A former Rhodes Scholar (in jet engine design), he brings to the role significant expertise in innovation, business development, technology commercialisation, venture capital and start-up creation. As CEO, Charles leads OISA and supports the Innovation and Science Australia (ISA) Board in its implementation of long-term initiatives to boost Australia's innovation, science and research systems. Prior to this role, Charles spent 15 years spanning the interface between business and research at companies including BCG and the University of Melbourne as well as work at Melbourne (Carlton) Connect and Melbourne Ventures.

PG 10

Dr. Collette Burke

Collette is Victoria's inaugural Chief Engineer. Since entering the field at 18 years old, she has gained several decades of engineering and construction industry experience. Having completed her PhD in risk management at RMIT, she is an internationally acknowledged researcher. Other roles Collette has held include Managing Director of Australian engineering consulting firm Exner Group and UAE based firm Karsta Middle East. She is also a director of VicTrack, and a former president and national director of the National Association of Women in Construction.

PG 40

Dr. Elanor Huntington

Elanor is a professor and the first female Dean of Engineering and Computer Science at the Australian National University. Armed with her PhD in experimental quantum optics, prior roles include Chief Investigator on several Australian Research Council projects, Program Manager for the ARC Centre for Excellence in Quantum Computational Communication Technologies and Honorary Fellow for Engineers Australia. She is currently serving on the boards of Significant Capital Ventures, Innovation Science Australia, Questacon and Science Advisory. As a Eureka Prize finalist and Telstra Women's Business Awards finalist, Elanor is passionate about reimagining science and technology for the future in particular for young women.

PG 28

Dr. Gordon Wyeth

Gordon is a professor and Executive Dean, Science and Engineering Faculty at Queensland University of Technology. His main research interests are in spatial cognition and biologically inspired robotics with more than 160 papers published in leading journals and conferences. He is a chief investigator in the ARC Centre of Excellence for Robotic Vision and has served as President of the Australian Robotics and Automation Association, chaired the Australasian Conference on Robotics and Automation, chaired the IEEE Robotics and Control Systems Queensland Chapter and is a Fellow of Engineers Australia.

PG 34

Jaqueline Linke

Jacqueline's capabilities lie in the arts, leadership, innovation, transformation, and optimising human potential. Currently, she is Associate Director for Leadership, Culture and Innovation at Transport for New South Wales, where she is responsible for building capability across the cluster for a future fit workforce. Jacqueline has worked in leadership, culture and innovation as a consultant, speaker, facilitator and executive coach to major companies and organisations in the private and public sector across the Asia Pacific region. She applies her artistic filter and innovation lens to optimise employee performance and achieve organisational objectives.

PG 70

Jenine Beekhuyzen

Jenine is the author of the internationally acclaimed book series 'Tech Girls are Superheroes'. As a strong advocate for technology innovation and diversity in STEM, Jenine oversees a national 12-week STEM entrepreneurship program and her expertise and impact has resulted in numerous awards, TV appearances and many published international research publications. With 18 years of research experience, she has educated more than 10,000 school girls with STEM entrepreneurship, has 66 peer-reviewed publications and is Founder/CEO of the international Adroit Research organisation.

PG 86

Dr. Jia-Yee Lee

Jia-Yee is an enterprise fellow at the Melbourne School of Engineering and the ARC Training Centre for Medical Implant Technologies. She plays a key role in fostering industry research engagement and developing research strategies with biomedical engineers at the University of Melbourne. A passionate advocate for entrepreneurship and the startup community, Jia-Yee is a mentor within CivVic Labs, a Victorian accelerator program, and advisor to a Melbourne start-up, Gobbill. Former roles held include project management within the Victorian Department of Health and Human Services and over twenty years in virology research. She has a PhD and MBA (Melbourne Business School).

PG 48

Grace Tudreu

Grace is a third-year international environmental engineering student at Monash University. Some student leadership roles she holds include committee membership of Female Engineers at Monash and Monash Association of Pacific Students. Grace believes environmental engineers are needed more today to find practical solutions that minimise the impacts of climate change in coastal regions and increase water accessibility in rural areas, especially for Pacific Island nations. She aspires to use the skills accumulated throughout her education to help her country and other Pacific Island nations, particularly in the areas of water sanitation and accessibility and flood mitigation.

PG 90

Graeme Henderson

Graeme is the Global Leader for Digital Experience at GHD Digital. With more than 25 years' experience in the resources, infrastructure, energy, manufacturing and professional services industry, Graeme has held various leadership roles, as well as several senior project, operations, technology and functional roles. Before joining GHD Digital, Graeme was Managing Director at Advisian Digital (a division of Worley) responsible for establishing Worley's digital strategy and then for the growth and development of Advisian Digital in Europe, Middle East, India and Africa.

PG 56

Gregory Millen

Gregory has leadership experience across innovation, design, technology and entrepreneurial ecosystems. Prior roles include revolutionising key services for British Airways' Frequent Flyer Program by developing a new experience model that employed bleeding edge technology to convert the offline business model into a data driven and software-based multi-sided market. Other clients include the New Zealand government, WeekZero, Bildify, Delta Airlines, Toyota, Saatchi, and eCom Scotland. He has addressed forums such as Eurus (a private capital forum) and produced papers on topics such as design and construction, health, energy, economic development and automation.

PG 82

Kumar R. Parakala

Kumar is President of GHD Digital based in Chicago. Former roles held include co-founder of technology firm Technova and Senior Consulting Partner at KPMG. He has worked with numerous Fortune 100 companies, boards and governments and served as President of the Australian Computer Society. In 2016, Kumar was awarded the ACS Digital Disruptors' International Professional of the Year and inducted into its Hall of Fame. Ranked in Australia's Top 50 in Technology, he is recognised as the one of the leading advanced analytics and artificial intelligence change makers in Australia. In addition, he is considered an accomplished speaker and thought- leader. Kumar is an alumnus of Central Queensland University and Harvard Business School.

PG 04

Larry Quick

Larry is a strategist with over 35 years of global experience in both the corporate and civic sectors specialising in disruption. He has designed, led, and facilitated countless strategic programs in Australia and the USA that draw upon his expertise in corporate strategy, innovation, transformation, social economic development, technology strategy, civic strategy, sustainability and resilience, and urban planning. As co-founder and Managing Director of Resilient Futures and original developer of the Strategy in Action framework, Larry now focuses his research and work on how organisations, people and communities can leverage disruption to generate sustainable value.

PG 62

Dr. Mark Cassidy

Mark is a professor and Dean of the School of Engineering at the University of Melbourne. A Rhodes Scholar, he has worked in numerous academic research institutions focusing on offshore geotechnics and engineering, predominately in developing models for analysing oil and gas platforms, mobile drilling rigs, renewable wave and wind turbines, anchors and pipelines. He has published over 300 peer-reviewed papers and holds three international patents with two naval engineering conglomerates. Mark is the recipient of numerous awards for his published research and is an elected Fellow of the Australian Academy of Science, the Australian Academy of Technology and Engineers and Engineers Australia.

PG 46

Jacyl Shaw

With two decades of international experience across industry and higher education, Jacyl is Global Director of GHD's Digital Innovation practice. Her expertise has been shaped through prior roles including a higher education strategic adviser, corporate lawyer, Supreme Court Judges' Associate and involvement in the entrepreneurial innovation ecosystem. Jacyl has a BA, LLB, LLM and a Master of Enterprise and hold several advisory roles. A co-founder of two start-ups and recipient of numerous scholarships and awards, she was awarded Microsoft Executive of the Year in the 2019 Women in Digital Annual Awards. Jacyl is an accomplished MC, speaker and facilitator and is passionate about making complexity accessible through creative storytelling.

PG 76

Jamie Leach

Jamie is the CEO and founder of Open Data Australia and a data technologist. She has an extensive background in project management, finance, technology and defence as well as leading data and technology companies through capital raising and global expansion. Jamie regularly advises and represents public sector and private clients on data strategy, privacy and protection, governance practices and raising the quality of data across the world. A frequent speaker and author on the transformative potential of data, Jamie is passionate about sharing global best practice and international trends.

PG 58

Janett Egber

Janett is the Customer Experience, Design Strategy and Planning Lead at Medibank and a key driver of the international 'Social Intrapreneurship' movement (League of Intrapreneurs).The movement focuses on strengthening culture within organisations to support people to identify problems worth solving and find the intersection between business strategy and social impact. Her diverse experiences include corporate innovation, strategic marketing, customer research and data analytics.

PG 16

Michelle Mannering

Michelle is a highly motivated, curious and compassionate leader with a keen interest in driving entrepreneurial culture and pioneering Melbourne's eSports industry. Michelle has founded several tech companies positioning her at the forefront of Melbourne's science, tech, eSports and start-up scenes. She enjoys opportunities to create awesome experiences and engage with the vibrant GitHub developer community. A recipient of multiple industry awards for her leadership and entrepreneurship, she is fondly known as the 'Hackathon Queen' and is an accomplished MC, speaker and facilitator.

PG 78

Dr. Mikel Alonso

For over 15 years, Mikel has thrived in complex, city-shaping projects where people come together to deliver outcomes that exceed expectations and benefit the community. In his role as GHD's Australian Transport Market Leader, he enjoys navigating ambiguity and high-pressure business contexts, as well as leading highly collaborative and diverse teams across Australia. Mikel is a Fellow of Engineers Australia and holds a PhD in engineering from the University of London.

PG 24

Myles Coker

Myles is an innovation consultant and engineer specialising in water resources at GHD Digital. He has over a decade of experience in Australia and abroad collaborating with industry partners to deliver engineering and research projects with a focus on integrated water management, innovation and commercialisation. President of the Australia's River Basin Management Society and a keen surfer, Myles is a published researcher in integrated water management and collaborator with the Waterway Ecosystem Research Group as part of Melbourne Water's Research-Practice Partnership.

PG 20

P-Cubed

Passionate about the environment, P-Cubed is a team of three primary school students from Queensland. The team have developed a free multi-platform app, Plastic Pollution Preventers, which will help young Queenslanders consider how much plastic they use in their daily lives and its environmental impacts. Saving our planet from plastic pollution is what drives them and their efforts have been recognised with numerous awards including national primary school winners in the Next Tech Girls Are Superheroes competition.

PG 88

Dr. Peter Cebon

Peter leads the Innovation Practice Program within the University of Melbourne's School of Engineering. He teaches masters-level students how to innovate and work in teams on ambiguous and challenging problems. His research and consulting work focuses on corporate governance in highly uncertain, disruptive environments. Peter holds a Master's degree and PhD from MIT and a Bachelor's degree from the University of Melbourne. He has over 15 years of experience teaching innovation and organisational management at the Melbourne Business School, Harvard University and ETH Zurich and has published over 30 articles, teaching cases and book chapters and edited two books on climate change and innovation in Australia.

PG 32

Dr. Peter Rathjen

Peter is a professor, Vice-Chancellor and President at the University of Adelaide. He is a scientist and medical researcher internationally recognised in stem cell science. A Rhodes Scholar, prior roles include Deputy Vice-Chancellor (Research) at the University of Melbourne and Vice-Chancellor of the University of Tasmania where he was instrumental in creating vibrant new university precincts within the Hobart, Launceston and Burnie central business districts. In June 2019, Peter was awarded the Officer of the Order of Australia (AO) in the Queen's Birthday Honours for distinguished service to higher education through senior administrative roles and as a scientist and medical researcher.

PG 42

Rachel Audigé

Rachel is a certified Systematic Inventive Thinking coach (SIT) with over 12 years of experience as a speaker, facilitator, trainer and advisor. She is passionate about helping people to think differently with 'inside-the-box' thinking that allows organisations to innovate using existing resources. Rachel is also a mentor for CSIRO's ON Prime program and a lecturer at the University of Technology Sydney. As well as participating in numerous international speaking engagements, Rachel has published two whitepapers and is currently writing a book.

PG 12

Richard Bolt

Richard has spent more than three decades striving for sustainable public value, including nine years researching policy for a Senate party, and 12 years heading large government departments covering energy, earth resources, agriculture, forestry, education, economic development and transport. With qualifications in engineering, public policy and management and company directorship, he is also Adjunct Professor of Energy Transformation at Swinburne University of Technology. In 2018, he was awarded a Public Service Medal in the national honours list however believes his greatest achievement is helping to raise four feisty, caring children, and becoming a newly minted grandfather.

PG 18

Richard Simpson

Richard has over 25 years' international experience leading major geospatial and BIM projects for improving asset performance. He has authored several books on this topic and serves on the executive council of the International Society of Digital Earth and is a senior Fellow at the University of Melbourne and Griffith University. Richard is also CEO of Meta Moto and his company has served diverse clients in the government, communications, transport, construction, investment and utilities sectors advising on digital twin strategies for several high-profile projects throughout Australia, New Zealand and Asia Pacific.

PG 64

Dr. Roger Hadgraft

Roger is a professor and civil engineer with over 25 years of experience improving engineering education through problem and project-based learning at research institutions including Monash University and RMIT. Roger was an Australian Learning and Teaching Council Discipline Scholar and co-author of the 'Threshold Learning Outcomes for Engineering and Information Technology'. He is currently Director of Educational Innovation at the University of Technology Sydney with a focus on curriculum transformation towards 21st century skills.

PG 38

Sally-Ann Williams

Sally-Ann is CEO of Cicada Innovations, Australia's home of deep tech. Prior experience includes Executive Program Manager at Google Australia for 12 years, where she was responsible for leading Google's efforts in CS and STEM education and outreach (K-12), research collaborations with universities and entrepreneurship and start-up engagement. Sally-Ann has contributed to the COAG STEM Partnership Forum and the foundation of StartupAUS. She is a non-executive board member currently serving on the boards of Fishburners and World Vision Australia. She is a mentor in the Startmate program, and has served as an adviser and mentor to several industry and university incubators and accelerators.

PG 52

Simon Bryant

Simon is Head of Digital, Data and Co-Innovation for Orange Business Services in Australasia. This role sees him engaged in building the new digital world by designing, delivering and operating industrial IoT, big data, analytics and AI-as-a-Service offerings for smart precincts, ports, construction, mining, logistics and transport enterprises. Simon seeks to achieve desired outcomes for enterprises through leveraging the power and potential of the data value chain to uncover and deliver insights that help improve the human experience, solve global challenges, achieve operational efficiencies and drive business growth. His prior experience has been with other global software and IT services businesses and their customers globally.

PG 60

Sylvain Emeric

Sylvain is the Australia Practice Director of Digital Innovation at GHD Digital. He specialises in digital and innovation strategy, innovation ecosystems, customer experience, service design, digital transformation and design thinking. He has a decade of experience delivering innovation strategies and programs of work that have resulted in new products, services, experiences or capabilities for clients across several industries including utilities, energy, banking, transport and logistic, education and government. Prior experience includes co-founding the design thinking practice at Capgemini Australia and Digital Customer Experience Lead at Capgemini Invent.

PG 14

Trent Clews-de Castella

Trent is co-founder/CEO of PHORIA, a Melbourne-based and globally reaching immersive technology company innovating in virtual and augmented reality (VR/AR/MR) with a vision focused on evolving technology that transforms the human experience for greater wellbeing and positive social impact. Trent was one of Forbes 2017 Top 30 under 30 for his leadership. PHORIA works with Google ARCore and Apple ARKit and last year teamed with Netflix and Google to co-create an augmented reality experience for wildlife documentary *REWILD Our Planet* narrated by David Attenborough. This opportunity demonstrated how AR has the power to build bridges between people and the places they love.

PG 74

Trish White

Trish has spent half her career as a professional engineer, executive and board director, and half as a politician and senior minister in the South Australian government. She is the immediate past National President and Board Chair of Engineers Australia and recipient of numerous honorary degrees and awards. Trish's parliamentary experience spans 15 years serving as a minister for Transport, Education, Science, Urban Development and Planning portfolios. She has also worked as an executive in the resources and energy industries, as well as in a portfolio of board director roles for companies in the infrastructure, transport, insurance, education and professional services sectors.

PG 30

Dr. Tuan Ngo

Tuan is a professor and Research Director of the ARC Training Centre for Advanced Manufacturing of Prefabricated Housing at the University of Melbourne and Director of the Asia Pacific Research Network for Resilient and Affordable Housing. A recipient of numerous prestigious awards, including the Eureka Science Prize for Outstanding Science in Safeguarding Australia, Tuan is considered a pioneer in Australia in the areas of Construction 4.0, off-site construction, design for manufacturing and assembly and sustainable and high performance modular building systems. He has published more than 300 journal and conference papers.

PG 46

Dr. Yee Lee Cheong (Dato Lee)

Dato Lee is the Commissioner of Broadband Commission for Sustainable Development at the UNESCO International Science Technology and Innovation Centre in Kuala Lumpur. He has been President and Chair for numerous industry organisations including the Institution of Engineers Malaysia, the Commonwealth Engineers Council, the World Federation of Engineering Organisations and the United Nations Millennium Project. Dato Lee is the founding secretary general of the Academy of Sciences Malaysia and founding President of the ASEAN Academy of Engineering Technology.

PG 44

Yohan Ramasundara

Yohan is the secretary general of SEARCC—the Asia Pacific Forum for Technology, immediate past President of the Australian Computer Society (ACS) and Federal Government Digital Leader for GHD Digital. Yohan represents Australia and the region at various international forums such as the World Economic Forum, APEC Telecommunications and Information Working Group and the International Federation for Information Processing (IFIP). He holds an Executive Certificate in Strategy and Innovation from MIT and several ICT, accounting and finance qualifications from the University of Canberra. He is currently authoring a children's storybook in his spare time.

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