FUTURE FRONTIERS

EDUCATION FOR AN AI WORLD

EDITED BY LESLIE LOBLE, TISH CREENAUNE AND JACKI HAYES

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NSW GOVERNMENT

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Foreword

Society today is mechanised and digitised. Successive revolutions in agriculture, industry and communications have created an ecology where human ingenuity and autonomy are augmented by artificial intelligence (AI). We have self-piloting cars, trains, boats and drones; we use computers that automatically trade our stocks; and we use Google Assistant or Siri to manage our diaries, make phone calls and check the weather.

Each day, with every new breakthrough in science and technology, it is becoming clear that we are racing towards a future with immense potential to drive productivity and improve standards of living across our community. Yet, in order to realise this potential, it is crucial that our education system is adequately resourced and is appropriately flexible to ensure that the next generation of students have the requisite skills to thrive in a rapidly changing world.

This is why education is the most critical area of government investment. The NSW Government is deeply committed to ensuring that education—from the earliest years through to higher education and beyond—best prepares citizens to navigate an AI-augmented world. This is evidenced not only through high-quality teaching and the implementation of a world-class

curriculum, but also through the building of new schools that enable students to learn in modern environments.

I am proud of how the *Education for a Changing World* initiative puts New South Wales at the forefront of thinking about the implications of AI for education. I warmly thank the leading academics and thinkers who have authored these essays. This collection challenges us to think deeply about how education responds to a fast-changing world and encourages us to pursue greater innovation across the education system.

I would encourage everyone within our education community to read *Future Frontiers: Education for an AI World*, so that we can frame opportunity in the face of uncertainty—and ensure that future generations enable New South Wales to emerge at the forefront of environmental, social and economic development.

The Hon. Rob Stokes MP
Minister for Education
New South Wales

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Introduction

LESLIE LOBLE

On 15 March 2016, a 33-year-old Korean man named Lee Sedol sat at a table, head bent, fighting back tears. A grandmaster in the ancient East Asian game of Go, and one of the greatest players in history, he had just lost 4–1 in a match series against an opponent named AlphaGo. Such tournaments don't normally attract much attention beyond the ranks of the game's devotees, but this one made headlines around the world because AlphaGo was an artificial intelligence (AI) program developed by DeepMind, a Google subsidiary.

This was a technical feat that most computer experts had said was still decades away. There are more possible moves in Go than there are atoms in the universe, and it is simply impossible to write for the game the kind of 'brute force' program that powers chess computers.

When I read the headlines, I was impressed in the way that one is by another 'flying cars' story. But when I learned *how* AlphaGo's triumph had been engineered, everything changed. Its designers had employed 'artificial neural networks'—computing

systems inspired by the arrangement of neurons in the human brain—that gave it the capacity for unsupervised learning. Nobody programmed AlphaGo for victory, nor for its surprising and innovative moves. Instead, the machine played millions of games against itself to develop and refine a strategy. AlphaGo had *taught itself* to achieve an intellectual feat that only a few dozen humans on the planet can approach.

As I read this, I put it together with other pieces of recent evidence: the phenomenal accuracy of today's language translation programs compared to just a few years ago; Siri, with its sense of humour; the sudden arrival of self-driving cars; the maturing of facial recognition as a corporate product and a tool of government; the intrusion of computers into intellectual professions like law and financial management; and the experiment where two AI programs invented their own language to communicate.

It was at that point I realised artificial intelligence isn't coming. It's here.

Powered by exponential increases in processing power and galaxy-scale troves of data, AI has blasted past predictions that scientists have made for it. If everyone was wrong in their forecasts about AI ten years ago, is the Future of Humanity Institute at Oxford right when they say AI could outperform humans in all tasks by 2060?

Suddenly, I found critical questions about education coming into sharper focus. In the unimaginable world that today's children will face when they leave school, what will they need to know? What skills and values will they need to lead rich and fulfilling lives? In a world where many of the tasks that make up their parents' jobs will be done by machines, what will our students need to draw on from their school education to thrive?

The search for answers to these questions placed this book in your hands. It is part of a wider project to bring the best minds to bear on the issue *now*. If we wait for education to evolve at its usual pace in response to change, it will be too late. When today's kindergartener is of prime working age and supporting a family, machine intelligence will have penetrated nearly every facet of daily life and corner of the workplace.

The issues at stake are enormous, and some messages that emerge from these pages are challenging. But you will find others inspiring. Looking into the future takes us back to questions as old as philosophy. What does it mean to be human? What is the true purpose of education?

Education was shaped in the 20th century by a search for closer links with the demands of the workplace. But in the 21st century we cannot think of education as imparting a bundle of skills and knowledge for a utilitarian purpose: machines are acquiring those skills as we speak, and we are swimming in a digital sea of information. As Richard Watson asks, is there any point to education when almost everything to be learned is available on the internet?

Of course the question is rhetorical, and steers us to a discussion that stretches across many of the essays in the book. For students to thrive in the future, they will need to be knowledgeable, curious, dedicated and nuanced learners, equipped with the skills that will enable them to hold their place in the world of machines. Some of these skills will help them harness digital intelligence. Others are qualities that set us apart from machines and define our humanity.

Collectively, we have come to call these qualities 21st century skills. Some of these are cognitive—things students need to know and apply. Others—dispositions and ways of dealing with learning and the wider world—we call non-cognitive. And then there are qualities of character and citizenship, which most of the authors in this book see as a third and vital component of 21st century education.

In the cognitive domain, high levels of literacy and numeracy will be essential, but not nearly enough. In 'Notes on the Curriculum', Marc Tucker makes a powerful case for a deep understanding of the 'big ideas' in the core curriculum. This will be just as important in the STEM (science, technology, engineering and mathematics) subjects as in the social sciences. Numbers, facts, raw computational power and analysis are easy wins for computers. The curriculum needs to equip students to play to their human strengths, so that people and machines can work together to solve problems that neither can alone.

Much public discussion of schooling in the 21st century calls for more and earlier instruction in computer skills like coding.

Certainly curriculum will have to change in this way, but it won't be enough. Jeannette Wing's intriguing interview on computational thinking shows us a pathway to a deeper understanding of the roots of computer science, insights that highlight our unique assets and offer the kind of human–machine partnership that will be a feature of the 21st century workplace: 'Computational thinking first and foremost is what humans do. Programming is an expression of a solution that a machine can understand'.

Understanding the conceptual underpinnings of computer science will not just be important for students heading for a career in that discipline. Rose Luckin's essay on the implications of AI for schooling makes the point that the need is far greater: 'Everyone needs to understand enough about AI to be able to work with AI systems effectively so that AI and human intelligence augment each other and we benefit from a symbiotic relationship between the two'. It is a message passionately echoed by many here.

Students will need to be able to critically evaluate information, understand how machines make decisions, identify the choices coded into algorithms and spot the ethical implications of every technological development. Toby Walsh's essay on the AI revolution offers an excellent summary of the moral dilemmas and traps of which we need to be wary. And consider this: already, facial recognition programs reportedly can assess a person's private sexual orientation with alarming accuracy. That fact alone should clinch the argument for an approach to computer science that fuses that discipline with a serious strand of philosophical and ethical inquiry.

Jeannette Wing's discussion of computational thinking throws up another curriculum issue with a bearing on the cognitive domain of 21st century skills. We tend to think of computer logic as binary: yes/no; on/off; one/zero. But as Wing points out, what distinguishes AI today is its ability to embrace uncertainty through probabilistic reasoning. So in the AI age a deeper understanding of probability and statistics will be important, as big data offers multiple pathways into old problems.

Curriculum may be the skeleton but teaching is the heart of learning. Quite a few authors here discuss the rising expectations

that will be placed on teaching if students are to go deeper and broader in their learning. Some call for rethinking how we teach. In a world where knowledge is instantly available, its value to students derives from their ability to critically engage with it and apply it to the solution of real problems in real time. For Marc Tucker, that means an end to the distinction between the 'hands on' learning that was once the domain of vocational education, and book learning—'the special privilege of the college bound'. In Australian schools the distinction is not quite as stark as he imagines, but the challenge Tucker identifies is very real: 'to make the courses in the core curriculum much deeper … and, at the same time, much more applied'.

Strategies for this include integrating real-life problems into existing subjects, work placements, project-based learning and longer-term assessments such as work portfolios. Many of these are collaborative activities that promote the development of teamwork: this takes us into the non-cognitive domain of 21st century skills. The capacity to work with others on a project or problem, to efficiently divide up tasks and harmoniously complete them, is vital in 21st century workplaces, especially as more and more teams are made up of contractors and freelancers.

Teamwork requires empathy, the ability to listen to the opinions of others, curiosity, leadership, perseverance. It starts with students understanding their own thinking—what they know and don't know—and extends to a capacity to both explain and listen, to challenge and adjust, to analyse what's known and search for what's new.

Crucially, non-cognitive skills can be taught, especially if we approach non-cognitive learning requirements with the same research-based evidence and rigour as for a history or maths curriculum. Several authors outline how these skills can be deconstructed into specific learning elements, scaled from basic to expert, and assessed in different ways and at different times. They highlight our need for greater research to identify more precisely what should be taught, when and how.

Rose Luckin explores self-efficacy to underpin much of what will enable today's students to prosper in the coming decades.

In an earlier age, imparting skills like motivation, perseverance and resilience might have been left to parents, or to inspirational school mottos. But today this 'growth mindset'—a belief in one's capacity to learn and to use failure to leverage progress—is deeply embedded in many big global corporations. Microsoft, for example, includes appetite for learning in staff performance appraisals and has strategies for encouraging growth mindset development.

So where once behaviours and mindsets might have been pushed outside the classroom to the sporting fields and elsewhere, they now are seen as essential by the authors here and well beyond. McKinsey's recent analysis of PISA data, for example, suggests mindsets can predict higher student achievement even for students in low-performing schools or with lower socioeconomic backgrounds, and there's a 'sweet spot' of learning that combines crucial teacher-directed instruction with a lesser but important amount of student-directed, inquiry-based learning.

Connie Chung's essay is valuable in placing the development of 21st century skills in a broader frame, linking them to the higher purposes of education in '[cultivating] in young people, ways to behave, be and belong with others in the world'. She lifts discussion of problem-solving and partnership skills above the workplace, reflecting on their power to enable young people to become creators who positively shape their work, family and local communities, encourage them to make good judgements about complex issues and consider the common good when making decisions.

She underlines the critical importance of skills of this kind in preparing young people for lifelong learning, and calls attention also to the need for well-developed social and emotional skills: 'Even and especially as technology becomes more ubiquitous in our lives, we may need to be thickening our social capital and our human connections with each other as we monitor and shape the development of AI'. You only need to reflect on the disquieting correlations between increased social media use and depression in young people to understand what she is driving at.

Most of the essays in this collection draw attention to the significance of developing in students an orientation to the values

of good citizenship as part of the preparation for life in a world dominated by AI.

Toby Walsh stresses the importance of ethics, society and civics because of the moral traps in computer code: 'If we are not careful, many of our hard-fought rights against racial, religious, sexual, age and other types of discrimination will be lost to machines that are not transparent, and that we should not trust'.

Richard Watson calls us back to the fundamental purpose of education: the creation of a fair and just society. If satisfying and rewarding work becomes the privilege of a highly educated elite, the system will eventually fail. He stresses an appreciation of diversity and interconnectedness, and the importance of extending and enhancing the characteristics that make us uniquely human—creativity, empathy and the ability to make moral decisions.

Marc Tucker sees it as part of global citizenship and growing pressures: 'In a very tightly laced world, empathy is the coin of the realm'.

Connie Chung says the essence of 21st century skills are those that can develop 'passion, purpose and principles'.

Underpinning all of this is the small solar system of 21st century skills that we call the capacity for critical thinking: a collaborative approach to ideas that is reflective and not reactive, self-corrective and not defensive, logical and not emotional, organised and not impulsive. Critical thinking is not achieved in contemplative retreat. It is integrally connected to human interaction and combines all three of the crucial education domains: knowledge, non-cognitive skills and 'roundedness'. Critical thinking may not just be the most valuable 21st century workplace competency. It is the most powerful tool we can give students to deal with uncertainty and change; to form productive, long-lasting relationships with others; and to participate effectively as citizens.

The roots of many of the skills and habits of mind we need to impart to students stretch back to the early years of life. Iram Siraj's discussion of nurturing 21st century skills in early childhood education and care is a powerful reminder of the opportunity presented by quality preschool education to instil the cognitive and non-cognitive skills that children will rely on so heavily in

the schools and workplaces of the future. With significant brain development occurring before age five, we ignore those early years at our peril.

Early childhood education will also be the key to one of the most important goals we will need to pursue in 21st century education: equity. The message from this book is that we need a new vision for education, and it has to be for all our young people. If we are raising the bar, we must raise it for all. If we are aiming to give students a broader base of ideas and a stronger schematic framework within which to engage with discipline content, it is because all students will need these. They will need them not just to find a place in the workforce but to take part in the crucial decisions that will confront all citizens in the years ahead. The demands on learning may be shifting but its core mission to educate all students well is more important than ever.

In making the changes that will be needed to meet the challenges of the 21st century, we should beware of the idea that there is a single measure that we can take today that will get us where we need to go.

It requires a system, not just a curriculum. In fact, the Australian Curriculum identifies many of the 21st century skills mentioned in this book. The tricky journey is from framework to practice.

Mark Scott's chapter gives us a sense of what that journey could look like. He is leading a dialogue between industry, business and the education sectors about the challenges they are grappling with, but just as important are the messages from the many NSW schools he mentions that have their own vision for change and innovation. These schools need the autonomy and local leadership to explore ideas, and the support and resources to locate and use the best strategies for their educational purpose.

Like many of the authors here, Mark Scott sees an important role for AI in education. But he makes the vital point that we have to start with education, not hardware, a message echoed elsewhere (in a House of Commons submission) by Rose Luckin: 'don't get seduced by the technology, start with learning'. The worst thing we could do right now would be to buy a 'killer app' and roll it out to every school in the system.

Used properly, AI offers a pathway to a goal long sought by the best teachers: learning customised for individual students and around individual subjects. AI can gather and make sense of a range of individualised data on student learning and feed it to teacher and student along with situation-specific learning tasks. Freed of the time-consuming processes of record-keeping, documentation and materials design, teachers would be able to spend more time on the higher-order Socratic role envisaged by Marc Tucker. But a transformation like this can't be technology-led. It can only happen in a culture of dynamic leadership, continuous self-reflection, professional assessment, and feedback for and among teachers at the local level.

Assessment is an important theme among the voices in this book. Richard Watson (among others) raises questions about the value of high-stakes testing across systems, offering a bracing challenge to standardised testing in general and PISA in particular. Connie Chung points to problems in the United States, where the skills that can be tested and measured end up receiving the most attention, sometimes to the detriment of non-cognitive skills that are harder (but not impossible) to assess. Mark Scott makes a similar point, and calls for more work on assessment instruments for non-cognitive skills. He draws a useful analogy with medicine to highlight the value of individualised, dynamic assessment used for diagnostic purposes.

There is one last, crucial theme across these essays: take the time to get it right. Our task is urgent, but at the same time we need to push past the slogans and the false divisions between 'content people' and 'skills people', or between 'test people' and 'project people'. To grab the latest fad will set us back. We need to hold onto what works even as we seek reform.

It won't be easy. As Connie Chung so eloquently writes, 'Teaching and learning is hard work. It is risky, high-stakes work, on which the futures of individuals, organisations, corporations, communities, nations and the planet depend … Yet teaching is rewarding work, which may be why it is worth the struggle …'

Whether in classrooms, living rooms or boardrooms, there is one clear call: we need to deepen students' learning so that they can ponder big questions, embrace doubt as an opportunity to

learn, engage with a diversity of views and give full expression to the things that make them human—their creativity, insight and empathy. If we succeed, we have given them the power to shape the future that they will share with this technology, and to prosper in the workplace and wider world.

CHAPTER 1

The AI Revolution

TOBY WALSH

We are in the midst of a revolution in which artificial intelligence (AI) is helping to transform our political, social and economic systems. AI will impact not just the workplace but many other areas of our society like politics and education. As with comparable events in the past like the Industrial Revolution, the road ahead may be bumpy in parts. This essay catalogues a number of the ethical challenges posed by AI. It ends with implications for the way our education system might help prepare society for this time of change.

INTRODUCTION

Rapid progress is being made today in the field of AI and robotics. This is being driven by four exponential changes:

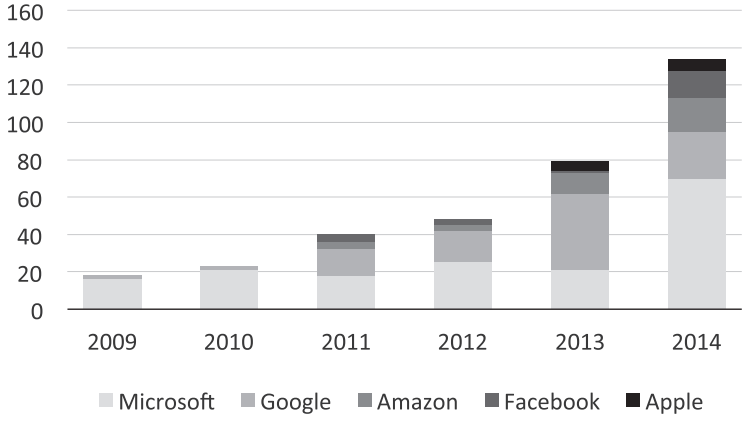
1. *Processing power*: Several decades of Moore's Law has doubled transistor counts every eighteen months. Computational problems that were previously impractical are now becoming possible.
2. *Data*: The amount of data online is also doubling roughly every two years. Smartphones in particular, and the Internet

of Things more generally, will continue this trend. This is providing datasets off which data-hungry techniques like machine learning (ML) can work.

3. *Algorithms*: Many decades of research into algorithms is starting to pay off. AI methods like deep learning are leveraging improved processing power and larger datasets to deliver exponential improvements in performance.
4. *Funding*: Venture and other funds are pouring into the field. Over the last five years, the number of acquisitions of AI start-ups has increased 50 per cent every year. The amount of venture funding being invested in AI start-ups is also doubling every two years. Large companies like IBM and Toyota are investing billions of dollars into AI research. A number of countries, such as Canada and the UK, have recently launched special government-backed initiatives in AI. An arms race is taking place in Silicon Valley between the big technology companies. This can be seen, for instance, in their patent activity.

These four ingredients, exponential increases in computer power, data, algorithm performance and funding are fuelling rapid advances in AI and robotics. Milestones are being passed in areas as diverse as transcription (computers now outperform humans at

Figure 1.1 AI Patents



transcribing spoken Mandarin), diagnosis (computers outperform the best doctors at diagnosing pulmonary disease) and warfare (computers outperform the best human pilots in air-to-air combat).

These advances will likely transform the workplace. Many jobs will be automated. It is not just blue-collar professions that are under threat but also many white-collar jobs in areas like journalism, medicine and law. As with any new technology, it is worth remembering that many new jobs will also be created alongside those that are destroyed. In addition, many jobs will be improved by automation, letting people focus on more creative, social and strategic aspects of the job while the machines do the routine and mundane. To understand the net effect, we must also take into account other factors like changes in demographics, the decreasing length of the working week, and the impact of globalisation.

I will not focus here on the challenges these changes to work pose to our education system. It will clearly require some significant changes in what we teach to equip students for these new jobs. The focus of this essay is on the other impacts this AI revolution will have on our economic, political and social systems, and on the many ethical challenges this will create. Given the speed of change, we need to start preparing soon.

WHERE WILL THIS ALL END?

We have no evidence to suggest machines will not eventually become smarter than humans.[1] But building machines that are as smart or even smarter than us is unlikely to be an easy goal to achieve. It is a major scientific and engineering project. The human brain is one of the most complex systems we know. Trying to match it in silicon is not going to be easy.

Most experts in AI estimate it will take at least fifty years to get to human-level intelligence in machines. Very few expect it will take much longer than a century. A serious research effort in 'AI safety' has begun recently to prepare for this moment and ensure that the goals of any such intelligent or super-intelligent machines align with those of humanity. Fears that the machines will take over anytime soon remain more the concern of Hollywood than the laboratory.

Before we get to machines as capable as humans, we will achieve what is called 'weak AI'—machines able to match or outperform humans in narrow tasks. Indeed, we have already done so in domains like playing chess and the ancient Chinese game of Go.[2] Such weak AI already poses many ethical challenges. In fact, weak AI will often pose more challenges than super-intelligence. It will, for instance, result in systems that fail in unexpected ways. And, as has already been seen with the first fatal Tesla crash, it will likely lead to systems that humans trust too much.

AUSTRALIAN AI

Australia is one of the countries close to the front of this revolution, punching above its weight in AI research. In August 2017, Australia hosted both the leading machine learning conference (ICML 2017) and the leading artificial intelligence conference (IJCAI 2017). A reflection of Australia's standing internationally is that it is the first country outside of North America to have hosted the IJCAI conference for a second time. In addition, there is a healthy start-up community in Sydney, Melbourne, Brisbane and elsewhere fielding AI technologies. And there are several industrial labs in Australia like Data61 and IBM Research with excellent track records of transitioning AI technologies into practice.

Australia has several natural advantages in this space. Our mining industry is already one of the most automated on the planet. Mines are an excellent place in which to develop robotics and automation, bringing both immense financial and safety benefits. Our finance sector is also well placed to take advantage of artificial intelligence. The ASX leads the world in the exploitation of new technologies like blockchain. Australia also has a number of other sectors like medicine, higher education and transport likely to be among the first to be impacted by AI.

Australia needs to be at the front of this revolution. We have a high-wage economy and many low-wage neighbours. We can only hope to compete with the efficiencies brought about by greater automation. With commodity prices falling, automation has kept our mines competitive. Australia is also cursed by distance, both within the country and to other countries. Around 10 per cent

of our GDP goes into transportation costs. Autonomous vehicles could drastically reduce these costs and provide a means of reducing CO_2 emissions.[3] They can also help combat the congestion that is choking our cities, save us from investment in expensive infrastructure, and provide personal mobility to disadvantaged groups like the elderly and the disabled.

The impact that AI will have on society will therefore likely be felt early on in Australia compared with many other developed countries. We will not have the luxury of observing what happens in the US or elsewhere. We will need to lead the way in adapting to the changes.

SOCIETAL CHALLENGES

I begin with several important challenges facing society that artificial intelligence raises: privacy, transparency, trust and fairness.

Privacy

Our privacy is increasingly under threat. As we shall see in many other areas, AI is both part of the problem but also likely part of the cure. Both business and government can now use technology to get unparalleled insight into our lives. With this comes great responsibility. It is much easier to end up with Big Brother if we have technologies, especially those based around AI, that can look into our lives at scale. The Admiral Insurance incident described here illustrates that companies are already experimenting with AI technologies that invade our privacy.

ADMIRAL INSURANCE

In November 2016, this FTSE 100 car insurance company announced a project to offer cheaper car insurance to young drivers. By reading people's Facebook pages using natural language processing (NLP) algorithms, they wanted to identify those new drivers most likely to be a good insurance risk. Following a public outcry, Facebook shut the project down, claiming it violated their terms of service.

Several lessons can be learnt from this incident. As is often the case, AI can play a part in both the problem and, potentially, the cure. On the one hand, AI technologies—in this case NLP—enabled the invasion of people's privacy. On the other, AI technologies could also enable the individual to control precisely what government and business know about them. The incident highlights how technology creates new opportunities in advance of the development of suitable laws or norms. Should companies be able to 'discriminate' on the price of your insurance based on your Facebook posts? Can companies be simply left to regulate themselves in this arena?

It is a little surprising that there has not been greater concern within society about the impact of technology on our privacy. The Edward Snowden revelations should have been a wake-up call to society about the potential abuses. Few technologists were surprised that our emails were being read. Email is one of the easiest forms of communication that can be monitored. Unlike other forms of communication like the telephone or post, email is already in a form that is machine-readable. In totalitarian states like East Germany, neighbour listened in on neighbour. But it is so much easier with AI technologies where computer can listen in on neighbour.

There is currently strong pressure on governments to invade their citizens' privacy. In the global war against terrorism, security agencies are struggling to find dangers hiding within society. It is tempting for them to use technologies like AI to look for potential threats. This raises many troubling ethical questions. If technology can make society safer, is it not worth the invasion of our privacy? Is our privacy invaded when only an algorithm and not a person looks at our data? If we have nothing to hide, should we care?

Transparency

Another area of concern is the transparency around decisions made about us as more and more of these decisions are handed over to

machines. Many current AI technologies are black boxes, unable to explain how they come to particular decisions. For example, one of the most fashionable and successful AI technologies currently is deep learning. This has been used in tasks as diverse as detecting skin cancer, pricing insurance and predicting crime. But deep learning cannot provide a good explanation for its decisions. It uses a complex network of 'artificial' neurons, one triggering another. In addition, how this network is connected and behaves depends on the massive amount of data used to train the network. Describing the network, the triggering decisions and training data likely gives little insight into a particular decision.

PHOTOS APP

In July 2015, a news story broke that Google's app had automatically labelled a black couple as 'gorillas'. The app had previously labelled dogs as 'horses'. Google's error was not unique. Other tech companies have developed racially biased imaging software. Flickr tagged black people as 'animals' and 'apes'. In Flickr's case, they also labelled white people as 'apes'. And HP's webcams were shown to be able to track white faces but not black ones.

Google quickly identified and fixed the error, not by having the program correctly label gorillas, but by removing the 'gorilla' label altogether. But there are many other areas where algorithms may be making similar mistakes without us realising it. In areas like credit risk assessment, job matching, online dating and product recommendation, algorithms are making decisions which impact our lives with very little transparency about how they work or why they make particular decisions.

As the image labelling examples above illustrate, we can unintentionally end up with damaging biases. Without transparency, we may never realise that certain groups are being discriminated against. In Europe, awareness about this issue is perhaps more advanced than elsewhere. In May 2018, the General Data

Protection Regulation (GDPR) comes into law. This requires that personal data be processed transparently, that meaningful information be provided about the logic involved in any automated decision-making, and that individuals have the right not to have decisions about them made entirely automatically. Such a law may become necessary here too.

There are also areas like national security where transparency is undesirable. We do not want terrorists to be able to know how threats are identified and monitored. A new scientific field at the intersection of game theory and computer science called 'security games' is under development to enable computers to allocate limited security resources in an optimal way that is unpredictable.

COMPAS

In May 2016, the non-profit investigative news agency ProPublica revealed that the COMPAS program, used by judges in twenty of fifty-two states in the US to help decide parole and other sentencing conditions, was racially biased. COMPAS uses machine learning and historical data to predict the probability that a violent criminal will reoffend. Unfortunately, it incorrectly predicts that black people are more likely to reoffend than they do. And it incorrectly predicts that white people are less likely to reoffend than they do.

With work, we could improve the program to predict correctly whether someone is likely to reoffend. But how do we know when we can trust such a program? And there remains the deep philosophical question of whether machines should decide on who is locked up. Are there some decisions we should perhaps not hand over to machines, even if they make them better than us?

TAY CHATBOT

In March 2016, Microsoft released the TAY chatbot onto the internet. TAY was designed to learn from the tweets coming

from its teenage audience and therefore to speak like a teenage girl. Less than twenty-four hours later, Microsoft were forced to disconnect TAY as she had been taught to be racist, sexist and highly offensive.

In putting TAY onto the internet, Microsoft made a number of fundamental mistakes. They should have put a profanity filter on the input and output of TAY. And they should not have left TAY to learn from the twittersphere without any checks. If a technology company like Microsoft makes such mistakes, you can be sure that we will see lots of similar mistakes from other companies in the near future.

TAY highlights a number of ethical challenges. Do chatbots have freedom of speech? Who is responsible for the actions of an AI program, especially when it uses machine learning and so is a product of both its initial code and the training data? How do we guarantee the behaviour of programs involving machine learning?

Trust

Closely connected to concerns about transparency are concerns around trust. How do we know when to trust a machine? What information provided by machines can we trust? Will we perhaps trust machines too much? AI will likely make these issues more problematic. When we observe a computer performing intelligently on one problem, we often tend to suppose it will work equally well on another. In reality, however, AI remains very brittle. Our smart computers can be surprisingly dumb when the problem changes even slightly.

In safety and security critical areas, there are already well-developed tools and techniques for the verification and validation of computer systems. Unfortunately, these tools and techniques struggle to scale to complex AI systems, especially those that learn and change, and that interact with a complex environment. We are even challenged in defining what properties machines should

have for us to trust them. What, for example, does it mean that an algorithm is racially unbiased?

Despite what high-tech companies like Google might have us believe, algorithms, especially those using machine learning, can be biased. Algorithmic discrimination increasingly will start to trouble society. If we are not careful, many of our hard-fought rights against racial, religious, sexual, age and other types of discrimination will be lost to machines that are not transparent, and that we should not trust.

Fairness

With economical, environmental and societal pressures mounting, countries are struggling to use their limited resources more fairly. As we start to hand decisions over to AI systems, we will want to ensure that they act fairly. In fact, computation can actually improve what they do. We can, for instance, have the system compute outcomes which are both fair and efficient.

Building AI systems that act fairly raises a number of ethical questions. What does fairness formally mean? For example, suppose we write a program to allocate organs to patients. How do we fairly treat patients of different blood type and age? At the same time, how do we fairly treat the different hospitals and states? How do we treat different ethnic groups fairly, recognising that some might be disproportionally present on the waiting list? And can we be fair to all these different actors simultaneously?

FACEBOOK

In June 2014, news broke that Facebook had secretly run an A/B experiment, not to improve their product, but to see if they could change the mood of their users. They altered the number of positive and negative posts in the newsfeeds of 689 003 randomly selected users. Users with more positive posts were observed to post more positively than users shown more negative posts. No ethics approval was sought for the experiment.

Not surprisingly, Facebook apologised. Several fundamental issues remain. When running tests involving the public, should

companies like Facebook and Tesla have to face the same ethical hurdles that researchers have to face at universities? Should companies be allowed to manipulate people's emotions like this? Do we need more regulation of technology companies? Is government giving them too free a hand?

POLITICAL CHALLENGES

Other aspects of our society will be affected by AI. We are already witnessing the impact of algorithms on politics and political debate. Cambridge Analytica, the data-driven political marketing company behind both the Trump presidential campaign and the pro-Brexit vote, is looking to expand into Australia. Using psychological data derived from millions of Facebook users, Cambridge Analytica tries to identify key swing voters. When do we cross the line from convincing to manipulating? Is a technological arms race between parties to target voters destructive to democracy? If we use algorithms to influence voters at manipulating scale, does it threaten our very democracy?

Another area of concern is fake news. Following Trump's election, many commentators suggested that fake news might have had a significant impact on the result. Facebook initially denied responsibility for the propagation of fake news. However, in February 2017, Facebook CEO and co-founder Mark Zuckerberg accepted some responsibility in an open letter. Interestingly, many of the suggestions he proposed for tackling fake news involved using AI. This is not too surprising. The only way you could filter hundreds of millions of posts each day is with AI-based natural language processing technologies.

A third political concern is freedom of speech. Who or what is responsible for the messages that machines produce? This is especially difficult to decide when machine learning is involved. The program may produce output that is very unexpected. What if the machine incites racism? How free is human speech when it is drowned in a sea of machine voices? It is estimated that over three-quarters of Trump's twitter traffic during the last presidential

election was fake supporters, Twitter bots that artificially boosted the Trump message.

HUMANITARIAN CHALLENGES

I end with a major humanitarian and ethical challenge introduced by AI. There is an arms race underway today to develop lethal autonomous weapons, or as the media like to call them, 'killer robots'. This will be the third revolution in warfare, after the invention of gunpowder and nuclear weapons. There are many reasons to fear this change. It will herald a step change in the speed and efficiency with which we can kill the other side. It will destabilise the current geopolitical order. These will be weapons of terror, and of mass destruction. Unexpected feedback between swarms of such systems may trigger unwanted wars, just as we see 'flash crashes' in the financial markets triggered by interactions between trading algorithms. As a result, many AI researchers and NGOs like Human Rights Watch are now campaigning for a pre-emptive UN ban on such weapons.

Lethal autonomous weapons raise a whole host of ethical challenges. How do we build robots that behave ethically? Could robots be built to follow international humanitarian law (IHL)? Could they distinguish adequately between combatant and civilian in the fog of war as required by IHL? Who is responsible for their actions? How do we prevent them being hacked to behave unethically? Should machines be given the right to make life or death decisions? Should there also be a human 'in the loop'? Many of these ethical decisions will be faced when we let robots into other parts of our lives. It is just that the setting of the battlefield makes the ethical choices even more stark.

HISTORICAL LESSONS

This is not the first technological revolution that has affected society, so we might look for lessons that can be learnt from history. Perhaps the closest parallel is the Industrial Revolution. This liberated us from the limitations of our muscles, transforming the nature of work. Before the Industrial Revolution, much of the world's population was occupied in farming. Automation

replaced many of these jobs so that today just a few per cent of the workforce is left in agriculture. New jobs were, however, created in factories and offices that employed those displaced from the fields.

In the Industrial Revolution, we still had a cognitive advantage over machines. It is less clear what advantages we will maintain over the machines this time. There is another reason that this time is different—not because it is special, but rather because last time was very special. At the time of the Industrial Revolution, the world took several large shocks which helped society to adapt to the change. Two world wars and the intervening Great Depression set the stage for what economists are now starting to recognise as an unusual reversal in inequality.

The introduction of the welfare state, of labour laws and unions, and of universal education began a period of immense social change. We started to educate more of the workforce, giving them jobs rather than allowing machines simply to make them unemployed. At the same time, we provided a safety net for many, giving them economic security rather than the workhouse when machines made them unemployed.

We might expect equally large societal changes will occur and will be needed for the coming AI revolution. A worrying lesson from history is that there was around half a century of pain at the start of the Industrial Revolution during which prosperity for many in society went backwards. It took some time before society adapted so that technological progress improved the lives of many.

IMPLICATIONS FOR GOVERNMENT

Motivated by these ethical concerns and historical lessons, I will identify a number of implications for government. All concern education one way or the other. This is because education is one of the most important and powerful tools at our disposal in adapting to the coming changes.

Teaching Ethics, Society & Civics

In fifty years time, we may look back at the next decades as a golden age for ethics. In handing over many of our decisions to machines, we will need to make explicit in computer code many

of our society's ethical choices. This will require us to have much greater clarity and consensus about what these ethical choices are.

With society under a period of significant change, we will also need an informed population to navigate this future, and to demand appropriate checks and safeguards. A citizenship educated in ethics, society and civics is therefore essential. The education system needs to prepare us for this future of 'computational ethics'.

Teaching Creativity

One of the advantages that humans have over machines is our creativity. Computers struggle to be creative. Machines are excellent at doing the routine and repetitive, and poor at coping with change and unpredictability. In time, I expect that machines will become as creative and adaptable as humans. However, for the next few decades at least, we will have a significant edge over machines in this area.

A creative population will be able to keep itself employed and ahead of the machines. Even if machines can be creative, they cannot speak to the human experience: about love, death, and all the things that make us unique. A creative population will also be able to take advantage of the free time that automation may give us. It follows that creativity can and should be taught more actively. If machines take over the sweat, this could leave us with the time to create the next Renaissance.

Developing Emotional Intelligence

Another advantage that humans have over machines is our emotional intelligence. Computers struggle to understand our emotions. And they have no emotional lives of their own. As with creativity, we are likely to have the edge over machines in jobs that require emotional intelligence for a long time to come. In addition, there will be an increasing value placed on social contact between humans. Emotional intelligence will therefore be increasingly important.

At present, our current education system focuses on lifting cognitive abilities. However, in some countries, like Germany, attention is also given to improving emotional intelligence. Classes in Germany will often have both a teacher focused on

the children's cognitive development, and an educator focused on their emotional development. This would be a good idea here too in Australia.

Universal Lifelong Learning

For many, education stops when they leave school or university. This is undesirable if we are to keep ahead of the machines.

We need to reinvent ourselves constantly, learning new technologies and adapting to the unexpected changes occurring within society. This requires an education system that gives us not just knowledge but learning skills, so we can learn throughout our working lives. We need to learn how to learn so that we can continue to learn even when we are no longer in a formal education environment like a school or university.

Government will need to support such lifelong learning, providing financial and other incentives to individuals and businesses to encourage the reskilling of the workforce. Ultimately, just as the Industrial Revolution made it essential that universal education was provided to the young, the AI revolution will make it essential that education is provided to people at every age of their lives.

Sea of Dudes

In Australia and the US, a major problem within the field of computer science in general, and especially within artificial intelligence, is the under-representation of women. This has been nicknamed the 'sea of dudes' problem.[4] The imbalance starts in secondary school. By the time university starts, it has become sufficiently extreme that any corrective measures merely put sticking plaster on the problem.

The under-representation of women in AI and robotics is undesirable for many reasons. Women will, for instance, be disadvantaged in an increasingly technically focused job market. It may also result in the construction of AI systems that fail to address issues relevant to half the population, and even to systems that perpetuate sexism. More initiatives are therefore needed to get young girls interested in STEM in general, and AI and robotics in particular. It will also be worth exploring why women are

better represented in other countries. For example, women make up 30 per cent of undergraduates in engineering courses in Spain compared with just 19 per cent in the US.

One Robot Per Child

In the 1980s, the UK Government kick-started computer literacy by introducing the BBC Model B computer into every school in the country. Many students also started to have access to low-cost computers like the Sinclair ZX80. At the time, there was significant scepticism about the value of giving children access to personal computers. What could they possibly learn from having access to word processors, spreadsheets and computer games? Two decades later, the UK found itself at the centre of the billion-dollar computer games industry. This is not a coincidence.

Providing one robot per child will likely have similar unexpected but valuable side-effects. It will, of course, have the primary effect of promoting literacy in AI and robotics. But it is hard to predict the secondary effects it will have. Perhaps Australia will become the centre of the industry which personalises robots. Or a major force in the robot entertainment business. It may even position Australia as a leading player in a new personal robotics industry that rivals the personal computer industry.

Any robots put into schools should have both software and hardware that is open so students can be creative with them. They should also come with tools to help students explore less technical issues like ethics and social relationships. There is evidence that access to robots, especially at an early age, can help bring girls into STEM.

Computational Thinking

We need citizens in our society to understand the fundamental principles of computation. If we don't, a large section of the population will be greatly disadvantaged, as much technology will simply be magic to them.

This doesn't mean we need to teach everyone to hack code. But we do want people to understand the building blocks of computation, to appreciate what can (and can't) be done, to

abstract problems so that they can be automated, to decompose problem-solving into a series of algorithmic steps, and to generalise to work across problem domains. These problem-solving skills will become essential in many new jobs. Robots will offer an excellent platform on which to teach such computational thinking.

Open Educational Data

Data in government should be opened up so that outside parties can innovate. Education should be at the centre of this open data revolution.

It will take some political courage to put education data at the centre of an open government, as this will, for instance, expose where the system is failing students. But there will be many benefits.

Education can become more evidence based. Parents and students can be more informed in their choices. Teachers can share best practice. Heads can identify areas in their schools needing improvement. Universities can target disadvantaged students who might not otherwise benefit from higher education. And high-tech companies like Google and IBM, as well as start-ups, can produce software optimised to actual learning experiences.

Government-wide Thinking

My final recommendation is for a government-wide report on how to prepare for the changes that AI and robotics will bring to society.

These are technologies that will touch almost every aspect of our lives. They will require changes to the welfare state, our taxation and pension systems, schools and universities, our legal system, police force and armed forces, our healthcare system, transportation and housing, even perhaps our political system. This is not a transformation where we can or should consider the different parts of government separately.

At the end of 2016, the White House Office of Science and Technology, and the Joint Committee on Science and Technology of the House of Commons and of Lords, both published reports on the challenges posed by AI and robotics. The US report especially contains some valuable recommendations. However, neither

addresses features specific to Australia like our particular demographics, our geographical isolation, or our urban characteristics.

The NSW Chief Scientist & Engineer, Mary O'Kane, was previously an AI researcher. She would therefore be an excellent person to chair such a report. The UK report recommended setting up a standing committee to monitor this area. Such a committee might be useful in Australia. Both reports also recommended more government investment in the area. If Australia is to compete in the worldwide AI arms race, it is likely that both government and business here will also need to invest more.

CONCLUSIONS

The AI revolution will transform our political, social and economic systems. It will impact not just the workplace but many other areas of our society like politics and education. We need therefore to start preparing for this future. There are many ethical challenges to overcome, ensuring that machines are fair, transparent, trustworthy, protective of our privacy and respectful of many other fundamental rights. Education is likely to be one of the main tools available to prepare for this future. A successful society will be one that embraces the opportunity that these technologies promise, but at the same time prepares and helps its citizens through this time of immense change.

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NOTES

1. Alan Turing refuted many of the common objections to intelligent machines in his seminal 1950 *MIND* paper which helped launch the field of artificial intelligence.
2. In 1997, Gary Kasparov, then the reigning chess world champion, was beaten by IBM's Deep Blue computer. In 2016, Lee Sedol, one the world's best Go players, was beaten at the game by Google's AlphaGo program.
3. Autonomous vehicles will be able to drive more efficiently, but this won't lead to a reduction in CO_2 emissions if we then drive more, live further from our work, consume more goods etc.
4. This phrase was coined in 2016 by Margaret Mitchell, then an AI researcher at Microsoft Research and now at Google. Her phrase highlights the fact that only around 10 per cent of AI researchers are women. Actually, she might have more accurately described it as 'a sea of white dudes'. Not only are most AI researchers male, they are also mostly white.

CHAPTER 2

Educating for a Digital Future: the Challenge

MARC TUCKER

I've been asked to write an essay on the challenges and opportunities of an artificial intelligence (AI) future for education and learning in school and beyond, and to tell you, the reader, what skills will be needed by your students when they enter the adult workforce, and the role of education in fostering those skills. But responding to that request in a serious way presupposes that we know—or at least I know—what kinds of challenges an artificial intelligence future will pose and what opportunities such a future will unveil.

What I know is that these questions are currently the subject of a spirited debate, a debate based on well-informed visions of an artificial intelligence future that range from the utterly dystopian to the unreservedly utopian. Whatever I might offer by way of suggestions to educators cannot, if they are to be useful, embrace the full range of dystopian to utopian images of the future. And so I begin by trying to help you understand developments in this very fast moving arena, sharing my own interpretation of the range of possible futures and then, and only then, telling you what I think the implications are for education policy.

The subject, however, is not one subject but many, all of which are very complex and all of which are evolving very quickly. The best I can do is skip lightly over the surface. I have for that reason ended this essay with a reading list, both to give you an idea of the sources I have consulted and to invite you to come to your own conclusions based on your own readings of these sources and the ones that are added every day to this literature.

For many educators, the definitive book on this subject is *The New Division of Labor: How Computers Are Changing the World*, by Frank Levy and Richard Murnane. Published in 2012, the book begins by pointing out that there have been repeated apocalyptic warnings about computers putting people out of work, but that future has not yet materialised. Levy and Murnane conclude on the basis of a wide-ranging review of the literature and a thorough analysis that it won't—or at least need not—happen this time either.

They tell us that intelligent machines are exceptionally good at executing algorithms conceived of as 'routines', which makes them better than humans at a wide range of low- and medium-skill tasks that essentially involve routine work. But, they say, as such jobs are taken over by the machines, putting people who only have what the educators think of as the old 'basic skills' out of work, other jobs—much better paying jobs—are springing up, jobs entailing extensive problem-solving, expert thinking and complex forms of interpersonal communication.

These authors were not pollyannas. They were worried that national education systems might not be able to provide vast numbers of people who now get only the basic skills when they enter the workforce with the much more advanced skills they would need for the jobs that would become available. If that did not happen, if educators could not produce a transformation in the skill endowment of national populations, then the job market would polarise, incomes would polarise and the resulting political tension could threaten our democracies. I came independently to much the same conclusions long ago and have been preaching that gospel for years.

Along the way, Levy and Murnane provide us with examples of tasks that workers do that AI will enable machines to do well.

They also give us examples of the kinds of tasks that the machines cannot do and will not be able to do for the foreseeable future. A prime example of the latter is driving a car. Their book was published in 2012. Only three years later, Google's cars began driving themselves down California highways. It is not just the example that is out-of-date. The whole analysis may be out-of-date.

Steven Pinker's *How the Mind Works* helped me understand how we got to 2017. Though it was published in 1997, it is still the best book on its subject. Pinker set out to write a book for specialists that would advance the field, while at the same time writing a book for well-educated generalists to introduce them to the field, and he succeeds. Pinker describes psychology as a discipline that for decade after decade did something that might be compared to trying to understand how a steam engine works without ever taking one apart. He is not kind to behaviourism, clinical psychology or any of the precursors to cognitive science, all of which still have an enormous influence on the thinking of educators all over the world.

Pinker points out that the people who pioneered artificial intelligence were rarely psychologists, and the psychologists, until recently, took very little interest in thinking machines. But, early on, the artificial intelligence community concluded that they could only make progress by conceiving of intelligence as a form of computation, the kind of computation that underlies information processing. The key to the success of cognitive science in unlocking the way the mind works is that it, too, defines intelligence as a process of computation. In the computer, the information-processing algorithms are implemented in silicon; in the mind, by cells and electric currents. There are limitations and possibilities in both mediums that are very different from each other, but cognitive scientists and artificial intelligence researchers are essentially studying the same thing: the algorithms that account for intelligence and intelligent behaviour.

The early version of artificial intelligence assumed that intelligence is what happens when humans invoke mental procedures in the form of algorithms that follow deductive logic. My 1987 dictionary defines an algorithm as 'a set of rules for solving a

problem in a finite number of steps, as for finding the greatest common divisor'. The same dictionary defines intelligence as the 'capacity for learning, reasoning, understanding and similar forms of mental activity'.

You noticed, of course, that there is a world of difference between these two definitions. The dictionary's definition of algorithm invokes the image of a deductive process that converts a set of inputs into a predetermined output using a set of tools that follow an inexorable logic. The definition of intelligence goes far beyond that to include learning, reasoning and understanding. The difference between the world that Levy and Murnane were looking at and the world in which Google's cars were driving themselves down Highway 101 in California is the difference between those two definitions.

Cognitive science and the artificial intelligence community both drew heavily on the computational theories of information worked out during and after World War II by Claude Shannon and other pioneers. But it was not until these two fields started to draw on each other, as each advanced, that artificial intelligence and cognitive science both really accelerated in a kind of intellectual symbiosis.

While that was going on, Moore's Law, predicting a doubling in computer speed and capacity every two years, was doing its work. Computers were becoming more powerful on a logarithmic curve and the development of global networks began to provide those computers access to unimaginable amounts of data. This was a formula for impressive developmental growth.

In the first instance, these technological developments made computers conceived of as powerhouses of deductive logic much more powerful than they had been previously. The IBM computer that beat the world's leading chess champion did it by computing all possible moves faster and more accurately than any human can. You might think of that as brute force computing.

But, at the time, shrewd observers noted that the same machine could not perform many of the cognitive functions that a normal three-month-old child could do easily. Nor could it demonstrate any of what most of us think of as common sense. It had no idea

what human emotions were, much less identify them in action, have them or respond to them. It could find and regurgitate information that was given to it, but it had no idea how to formulate a problem nor was it able to learn how to do something it had not already been taught to do. This is the world that Levy and Murnane were writing about.

It turns out that playing chess is a very bounded problem, one very suited to deductive logic and sheer computing power, but one cannot assume that a machine that can beat the world's chess champion is an intellectual giant. All in all, a three-year-old is much smarter. But a few years after Levy and Murnane wrote their book, a Google machine won a game against an expert player of the Chinese game of Go. There are almost an infinite number of possible moves in that game. It cannot be won in the same way as a chess game can be won. Go players win by a kind of intuition based on pattern recognition. It is a very human kind of cognition, the kind we developed to assess a very complex situation almost instantly on the savannah quickly enough to avoid getting killed there 200 000 years ago.

By that time, Levy and Murnane had been proven right … at warp speed. Waiters and waitresses were being put out of work by iPads stuck on dining tables that enabled the customer to place an order and pay their bill. Grocery clerks were being replaced by machines that automated the check-out lane and took automatic inventory. Miners were being replaced by automatic mining machinery which not only did the mining but took the ore to the surface, loaded it on driverless trucks, offloaded it onto automated trains and then automatically put the ore on the ships that would take it to China. Automated equipment had long since replaced the petrol station attendant. Robots were being ordered by the millions to replace the Chinese workers who had been making the laptops, smartphones and ink jet printers sent from the country's coastal provinces all over the world. These developments were not only idling literate but only moderately skilled people by the millions in the developed world, but were also removing rungs from the ladder the people in the developing world had been climbing to join the developed world. In the US, manufacturing accounted for

as much of the gross national product as it had thirty years earlier, but accounted for a much smaller fraction of total employment. Machines were rapidly replacing humans on the factory floor.

But Erik Brynjolfsson and Andrew McAfee describe another effect of the advance of intelligent machinery that is less well understood by the general public and no less important, in their seminal book *The Second Machine Age: Work, Progress and Prosperity in a Time of Brilliant Technologies*. It has been described as the 'winner take all' phenomenon. These authors use the example of the Eastman Kodak company to make the point. At its height, Kodak employed more than 145 000 people helping others share billions of photos, as well as thousands more in its supply chain. And then it went bankrupt, a victim of the conversion to digital photography. A team of fifteen people at Instagram developed an app which was also used by customers all over the world to share billions of photos. Fifteen months after they founded the company, Instagram was sold for over US$1 billion to Facebook.

Everywhere we look, small groups of very highly educated and trained people are creating applications (think algorithms). The first one costs a great deal of money. But the next copy costs virtually nothing, and the one after that and the one after that cost no more. More often than not, the product can be used all over the world. A small group of people in San Francisco run a worldwide taxi company, putting countless taxi companies out of business. They own no taxis, only the rights to an algorithm. They are now developing taxis that will drive themselves to customers who will call them with their smartphones and pay them with the same smartphones. No taxis, no drivers, no clerks, no dispatchers. Why pay to listen to a local musician when you can hear the world's leading musicians for next to nothing on your smartphone? Why go to the mall when you can sit in the comfort of your own home, comparison-shop worldwide and have the product you are looking for at a great price delivered to your door for nothing? Department stores are going bankrupt and malls are closing all over the developed world, and the people who used to work in them are being replaced by apps and machines controlled by the companies that got there first. A handful of winners become very, very

rich doing this, but a great many people are ending up less well-off, on contingent employment or simply unemployed.

The first stage of machine intelligence extended this line of work by incorporating the accumulated craft and intuitive knowledge of renowned experts in a variety of fields into the machine's database, in a process called 'knowledge engineering'. The knowledge—which could include, for example, the diagnostic knowledge of renowned doctors and medical researchers—was certainly not routine, but putting that knowledge at the disposal of rural family doctors did not involve machines that could learn something that was not already in their database, nor did it require the machine to demonstrate intuition, distinguish someone who is sad from someone who is happy, have the common sense of a six-month-old child or communicate to an artificial leg with electrical signals all the information the brain normally supplies to a real leg required for it to accomplish the incredibly complex movements that all of us make countless times every day.

The situation is very different now, since Levy and Murnane wrote their book. When researchers played a classical music concert to a group of expert critics recently and asked them which piece they preferred, the majority selected a piece written by a computer that they praised for its emotional power. They were enraged when told that it had been written by a computer. Music companies are now employing computers that analyse popular music to find out what distinguishes the platinum hits from those that do not do so well, and the computers then write original songs that mimic the best. Computer programs are now capable of minutely analysing ordinary human speech to discover the patterns that correspond to various human personalities, and using that information to match people who call in to customer service centres to staffers who will make them feel comfortable. Popular real estate websites feature software that estimates the value of homes both on the market and not on the market using the same factors and values that licensed appraisers use, putting the appraisers out of business. Other programs can discern from the patterns of relationships among the features on people's faces what emotions they are feeling and change the content of ads in response. There are now programs that

will enable soldiers whose limbs have been blown off and replaced by artificial limbs to communicate with and thereby control those limbs with their thoughts alone. Some of the biggest investment companies in the world are replacing their very highly paid analysts with algorithms that seem to be making investment decisions just as sound as those made by the people they replaced. None of this sounds like the routine work described by Levy and Murnane.

Perhaps the most interesting recent development is machine learning. The current version of the *Oxford English Dictionary* does not define 'algorithm' as a set of rules for solving a problem. It defines algorithm as a 'process or set of rules to be followed in calculations or other problem solving operations …' What could a problem-solving process be if not a process involving following a set of rules, especially if we are speaking of a process that is best described as information processing? What if I told you that what we are speaking of here is decisions made by intelligent machines on the basis of inference rather than deduction, on the basis of probabilities rather than hard facts, on the basis not of what has been programmed into the machine but what it decides it has to learn from data it decides to gather? What if I told you that when expert programmers look at the algorithms driving the most advanced machine learning systems, they have no idea how the machines reached the conclusions they reached because there is no train of deductive logic for them to follow? The machines are deciding for themselves what to do and how to do it.

The new generation of machines is eager to learn. Give them a goal, a set of algorithms and a mountain of data and they will learn what they need to learn to reach the goal, remarkably quickly. They will develop a theory—it could be wacky—then test the theory out on the data. It might work a little. It will change the theory a bit. It might work a little better. The machines will keep doing this over and over again until the theory not only explains the data they started with but also a great deal of new data they get their hands on. This is the essence of human intelligence. The search for patterns that explain a great mass of seemingly unrelated phenomena is what Einstein was doing in the Customs office. It is a long way from brute force calculation.

What has made this possible are enormous advances in information-processing speed, the ability to see patterns where before they saw only confusion, the sophistication of the algorithms available to them and access to enormous amounts of data, courtesy of the World Wide Web and the very large databanks being assembled by businesses, government and researchers. While all of that has been going on, other people have been making rapid advances in sensors of all kinds and in the degree to which these intelligent machines are at home in the world, speaking here of the kinds of things that are second nature to a six-month-old but have been very hard for intelligent machines. They have not yet made machines with the flexibility and skill of the human hand, nor do these machines yet have the common sense that a six-month-old has, but remarkable progress is being made and there is no reason to believe that it will not continue.

While it is still true that there are vastly more connections available in the human brain than in any computer, computers are much faster than the connections in the brain and are now connected to a worldwide memory bank far larger than any human's long-term memory. This is a recipe for a subtle, flexible and powerful intelligence. It is no longer a question of what the machines can do; it is a question of what they cannot do, a domain that is getting smaller quickly.

Four years ago, Carl Benedikt Frey and Michael Osborne, a pair of Oxford University researchers, calculated that half of the jobs in the US economy could be automated by equipment when available. More recently, McKinsey & Company, a consulting organisation, completed a more sophisticated analysis. Combining a list of the functions that intelligent machines can now accomplish and running that against a detailed description of thousands of different kinds of jobs tracked by the US Department of Labor, they looked at which parts of those jobs could be done by the machines and which parts could only be done by humans. McKinsey concluded that fewer than 5 per cent of American jobs will be fully eliminated by intelligent machines. Their report envisions a world in which machines and humans do most jobs together, welded at the hip. That is rather more comforting than the Oxford report.

But consider one of the jobs McKinsey analysed: retail sales. One of the functions of a retail salesperson is greeting customers, which, according to McKinsey, requires such capacities as 'sensory perception', 'social and emotional sensing' and 'natural language generation', which the machine, it says, cannot yet do. But retail malls, as I said above, employing very large numbers of people, are closing all over the US, as are the giant department stores that used to anchor those malls, because customers prefer to sit in their living rooms ordering the stuff they used to buy in malls from Amazon. Amazon employs far fewer people than worked in the establishments it is replacing. And, even so, Amazon is working hard to replace many of the people in their warehouses with automated equipment. Another version of the Kodak story, but on an even larger scale.

In this case and many others, the McKinsey analysis makes very little sense to me. Ignore for the moment the fact that intelligent machinery is available right now that is quite good at sensory perception, social and emotional sensing, and natural language processing. Focus instead on the fact that Amazon did not deconstruct the job of the retail sales clerk and then use machines to do only the 'automatable' parts. They did an end run around the whole retail enterprise, which is precisely what is occurring in one domain after another.

The consequences are all around us. Not only are we seeing job categories employing millions of people suffering as a consequence, but it is now clear that those people who have become underemployed or unemployed as a result of the introduction of these technologies are not getting new jobs that will enable them to live as well as they did when they had the old ones. One of the most important reasons that the advanced industrial nations have not seen wage inflation as they have been recovering from the Great Recession is that so many people who used to have full-time, well-paying jobs are now willing to take part-time jobs and jobs paying much less than they used to make, because they do not have the skills needed to join the ranks of the fortunate few who do the high-paying jobs that are available.

It was not the former production workers at Eastman Kodak who wrote the Instagram apps. The few who do have those remarkable skills are able to command astronomical salaries, benefits and stock options, to say nothing of working conditions that might have been envied by King Tut. But there are very few of them, and their ranks are not increasing at anything near the rates that jobs for those with less esoteric skills are declining. Average productivity is not rising the way economists expected it to because, while a few people are much more productive, many are much less productive.

The results are very sobering. A recent book, *The Vanishing Class: Prejudice and Power in a Dual Economy*, by Peter Temin, an MIT economist, tells us that a model used by Nobel prize–winning economist W Arthur Lewis more than seventy years ago to explain the economics of low-income developing countries perfectly describes the US today as a dual economy, with islands of rich people who have most of the investable savings surrounded by a much larger group of people just trying to get by. Larger and larger fractions of the working-age population in the US have been dropping out of the workforce, unable to find work at all, so dispirited and depressed that they have become the epicentre of the national epidemic of opioid drug abuse. The American economy is splitting into two pieces. One piece—highly educated and skilled—is benefiting hugely from the new technologies I have been describing—at least so far—and the other, undereducated and less skilled, is being put out of work by them.

The idea that the people I have just described should be thought of as surplus labour and put on a permanent dole has left the realm of the think tanks. Countries and cities in the developed world are now implementing policies based on that idea. The future has arrived. The political tensions that inevitably accompany increasingly polarised incomes and opportunities are now on view on the evening news programs on TVs all over the developed world.

It is not a law of nature that the introduction of new technologies will put a lot of people out of work in the short term, but will then create just as many new jobs that are even better in the long term. What is distinctive about these technologies is that

they incorporate the very thing that makes us so different from any other thing, animate or inanimate, on earth: high intelligence. We have gotten inside the black box of the mind and have been very busy reverse-engineering it. It is now becoming clear that intelligent agents already exceed human capacity in some domains of intelligent behaviour. The only question is whether they have the potential to exceed humans in all domains of human intelligence, and, if they do, how long it will take to get there. In this crucial sense, these technologies are unlike anything we have seen before.

Reading all of this material has led me to two conclusions. One is that the first stage of the evolution of these technologies is well advanced in its implementation and is now driving the economic divide I just mentioned. That stage has been characterised by what is becoming a vast extinction in the advanced industrial countries of the kind of jobs requiring basic literacy that the industrial model of public education was designed to prepare most graduates for. If that were the end of the story, the solution would be to redesign our education systems to prepare all of our graduates for the kind of work that our elites have been doing—professional work requiring complex thinking skills, deep knowledge in multiple domains, strong communication skills and social skills, strong values and strong character. That is an enormous task, but one that a growing number of countries are learning how to do.

But that is not the end of the story. I have come to the conclusion that the first stage will be succeeded by a second stage in which the utopian and dystopian possibilities I described earlier loom into view—a world in which intelligent agents take on more and more tasks now done by humans and accomplish many of them more effectively and efficiently than humans can do them; a world in which it becomes harder and harder to distinguish the human from the machine as we find more and more ways to alter our genes and augment not just our motor capabilities but our emotional and intellectual capabilities with intelligent agents.

If the human community continues on its current course, Yuval Noah Harari's vision of the future seems all too probable to me, a future in which a small number of humans manage to become literally immortal and to live forever a life of immense power and

wealth; a larger number may live quite well—though not forever—in the style of Renaissance artists, thinkers and craftspeople, serving the ultra-wealthy; and the vast mass of the people thought of as surplus labour are paid out with a universal basic income. It is all too possible that will be a world, again like Renaissance Italy, in which the wealthy clans are constantly duking it out with the other clans, only this time with weapons of unimaginable destructive power. That is not a world I want for my grandchildren—that is, after all, whom we are talking about here—even if they are able to become members of one of the first two classes.

The utopians have a point. We may indeed be on the cusp of being able to cut and edit our genes so as to eliminate a vast range of diseases, feed the millions with nutritious foods grown in a way that will not poison the planet, process all our waste to turn it into the resources we need to provide for everyone, and in general, provide a good life to virtually everyone while restoring our home—planet earth—to health. Doing that would require a human population with great imagination and high skills. More than any technical skill, it would require a very high order of political skills, not just on the part of our political leaders but also on the part of the citizens who vote for them—or fail to do so.

If we succeed in this venture, most people who want to do so could lead a life of leisure filled with creative and rewarding activities—social, artistic, intellectual. There could be plenty of what we now think of as work for those who wanted it.

But to get there, we would have to reconceive how the bounty I just described could be created and distributed. Human beings were born to work. Our survival depended on it and so the work we do became for many of us the source of our pride and our identity. The idea of a dole for our surplus labour flies in the face of that reality. If intelligent machines end up doing most of the work that is needed to provide the stuff and the services we need and want, we will have to reinvent our social and political and economic systems to make the arrow point towards the more utopian visions rather than the more dystopian ones. That cannot be done by a few political leaders acting on rare foresight on their own. It will have to be done by the people.

I conclude from all this that the prescription I shared above calling for the reshaping of our education systems so that all students are offered an education previously reserved for an elite is correct but not enough. Yes, many more students will need strong cognitive skills, much deeper knowledge and much more sophisticated skills in general, if they are going to be partners to increasingly intelligent agents and not be put out of work by them in the near to intermediate term. And they will need to be very strong where the intelligent agents are, at least for the time being, relatively weak—in areas like creativity, imagination, and the whole range of social and emotional and communication skills that will be the necessary complements to intelligent agents.

But that leaves out what I take to be the decisive factor as the second round of the development of intelligent agents gathers steam: the question as to what it will mean for our lives together and for what it means to be a human being, for the distribution of opportunity and wealth and fulfilment. It is in this realm that education may turn out to be decisive in determining the future of humanity. Answering the question of what it means to be human has never been more urgent. The need to understand history at a deep level in order to prepare ourselves for the future has never been more urgent. The need to enable students to understand others very different from themselves and to be able to see the world from their point of view is essential if we are going to avoid blowing ourselves up on the way to utopia. The liberal arts are disappearing from colleges and universities in the US as students, increasingly anxious about their economic future, focus their time on their vocational goals. But the liberal arts—reconceived—may be the key to our survival as a species.

It is essential that we reconceive schooling not just in terms of greatly ratcheting up the standards of students' cognitive development, and not just adding to that the need to provide in a very deliberate way for the development of students' communication, social and emotional skills and, more broadly, their character, but also to reconceive the curriculum in a way that will prepare students for citizenship in a way and to a degree that is totally new, for a world that will call on them to make unprecedented decisions

about the structure of their societies, the structure of their economies, the nature of work and their responsibilities to others in the place that intelligent technology is creating. Above all, it must be a curriculum that is about values, about what it means to be human and what we value about being human. If we fail at this task, it may only be a matter of time before the machines and a very small technological elite are deciding these issues, and we are not likely to be happy with their decisions.

READING LIST

I'd recommend four books to start with, read in the following order:

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Ford, Martin (2015). *The Rise of the Robots: Technology and the Threat of a Jobless Future*. Basic Books, New York.

Pinker, Steven (1997). *How the Mind Works*. W.W. Norton, New York.

Harari, Yuval Noah (2017). *Homo Deus: A Brief History of Tomorrow*. Harper-Collins, New York.

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CHAPTER 3

On Education in the 21st Century

RICHARD WATSON

There's a scene in the classic Woody Allen movie *Annie Hall* where the nine-year-old Alvy Singer has been taken to see his doctor because he's become depressed. His mother, who is at her wits' end, points out it's because of something Alvy has read in a book. Alvy explains the problem: 'The universe is expanding, someday it will break apart and that would be the end of everything'. 'He's stopped doing his homework', his mother adds, to which Alvy responds: 'What's the point?'

This is a more imaginative version of 'the dog ate my homework' excuse, and while it's a little early to be getting metaphysical, one might expand Alvy's point about there being no point to inquire about the purpose of education in an age of information on demand, kindergarten robots and artificial intelligence. In an era dominated by the internet, mobile devices and screens, why would one need to physically attend school? Surely everything you need to learn can be accessed from home? Moreover, why bother with spelling, arithmetic or even languages if Google can do all

this for you? In fact, why bother learning anything at all if you can access everything from anywhere at any time? What's the point?

FAST-FORWARD TO THE FUTURE

I am aware of university students refusing to attend lectures because they prefer to download their lectures and watch them at their own convenience at 1.5 times speed, rewinding anything that isn't instantly clear or understandable. But what's the point of even this if advanced machine learning and autonomous systems are capable of doing almost everything humans can do at a fraction of the cost? Under the current system, are we not teaching the next generation to become rapidly redundant in the face of accelerating technological change?

We've been here before many times, of course. Machines have a long and rather repetitive history of stamping out human skills, and while it may be true that the scale and the speed of change are different this time, they might not be. We would therefore do well to remember the sage piece of advice contained in Douglas Adams' book *The Hitchhiker's Guide to the Galaxy*, which is 'Don't Panic!' We repeatedly overestimate the impact of new inventions over the shorter term, and while many superficial things are changing, many deeper things are not.

On the other hand, the only thing we can say with absolute certainty about the distant future is that it's uncertain. It is therefore surely our responsibility as adults and educators of future generations to ensure that our children have a decent future. So we should make mild preparations for a number of different outcomes, especially any that currently appear unfavourable. After all, if just about everything else is being digitally disrupted, why not education? Surely education is one of the last bastions of the analogue, and unless educators start to think about how to maximise the upsides of digital technologies they will rapidly fall victim to the digital downsides.

The educational system that exists in Australia today is one largely shipped over from England in the 19th century when the economy was based upon agriculture, repetitive work and skills that generally resulted in jobs for life. These jobs weren't necessarily

interesting, but they did involve physical activity and provided identity and meaning alongside money. This system worked fairly well back then, especially when most workers didn't have to think for themselves.

But the system arguably works less well now when individuals are increasingly paid for their ideas or their ability to manage or motivate others. The system nowadays is also one where individuals are increasingly responsible for the creation of their own lifetime employment. Thus, an appreciation of how one sells oneself in an entrepreneurial context might be useful.

I'm a little reticent to suggest that education needs to be reinvented, partly because many aspects of the system work perfectly well, and also because one of the big problems that education suffers from is endless attempts to reinvent it. You'd think that after 150 years or more we might have learned how to teach, but apparently not.

THE LEANING TOWER OF PISA

Every time a freshly caffeine-infused official is put behind a desk, there seem to be panicked cries to move forwards (or sometimes backwards) to compete with countries towards the top of the PISA global education rankings, namely: a) Singapore, b) China, c) South Korea, or d) Finland.

This is a little odd because a) while Singapore is good at memorisation it has an issue with creative problem-solving, b) so does China, c) ditto South Korea, which by the way has a mental health epidemic largely caused by the pressure of a somewhat binary examination system, and d) Finland was a late developer educationally speaking, so it's fairly easy to dazzle from a distance and demonstrate high gains from a relatively low base.

Finland also unintentionally games the PISA system by doing well across a narrow band of conventionally academic subjects. If you measure student happiness in Finland, for instance, the country is at the bottom of the class. Youth suicide is high in Finland (as worryingly elsewhere) and economically the country is one of the weakest in Europe.

PISA, like its namesake tower, looks distinctly wobbly.

The OECD claims that PISA tests assess whether students have acquired key knowledge and skills that are 'essential for full participation in modern societies'. They would say this because it's the OECD, but the tests pay little or no regard to cultural or regional context and, more importantly, do not assess how individuals perform or feel about themselves across the whole of their lives. These tests are largely a snapshot of economic preparation, not a measure of lifetime happiness, mental wellbeing or physical health.

So my first suggestion to anyone involved in education in Australia or anywhere else is simply to stop. Stop with the endless proclamations, denigrations, exemplifications and modifications and allow the fine dust of any recent educational reforms to settle. And ignore PISA.

Then, when the air has cleared, pat yourselves on the back for doing a good job with limited resources and little in the way of thanks from students, parents or anyone else. Only then should you start to think about what education in Australia might look like in the future and how it might serve society in the broadest and most useful sense.

THINK. AGAIN.

When I say think, I don't mean cursory glances, snatched snippets or measly morsels. I mean huge heaving plates of contemplation capable of exciting or frightening anyone coming within a country mile of them. Think wide-open spaces of unpopulated possibility. Think curly whirly thoughts that would make Doctor Seuss and his Cat in the Hat grin from ear to ear.

Think about how you'd do things differently if you were building the education system from scratch. A new system with no legacies or liabilities whatsoever. One in which resources, the media, the unions, politicians, parents and the business environment weren't a factor at all. What would you do? More importantly, perhaps, what would you stop doing? Spend about a year thinking about this.

A year? I can already hear calamitous cries coming from the corridors of Canberra. But seriously, what is the rush?

This is serious. There are undoubtedly things that are more urgent, but I struggle to think of anything that's more important than the education of future Australians.

GET SMART

In the past, Australia has been a lucky country. To remain so it needs to become a smart one too and the only way to achieve this is through education, not digging large holes and exporting the contents to China. This isn't sustainable.

You've most probably got one shot at major reform for the next generation, so take your time and don't waste theirs. If you can't come up with any earth-shattering thoughts, no worries. Just leave things alone and focus on hiring the very best teachers you possibly can. Also constantly reinforce the idea that literacy and numeracy are the foundations upon which everything else is eventually built.

I'm a fan of Slow Education, which, like Slow Food, teaches us to take our time. Both Slow Food and Slow Education are people-centric, reflective and aim to ensure that individuals appreciate where the things they consume come from. Both emphasise the importance of local difference, craft and quality over standardised production and cheap ingredients.

For me, Slow Education is about the pleasure of the process as much as any potentially illusory destination or outcome. It is about classroom interaction, conversation and the slow unfolding of understanding. It is also a reaction to pushy parents and tiger mothers who see all lessons in the context of prestigious professions and the making of money.

Slow leadership within education might ensure that the influence of such parents is kept to a minimum. Explaining to a five-year-old that there's a good chance they'll live to become a 100-year-old might also ensure some much-needed perspective. Slow learning obviously has some negative associations, but one of the biggest problems we've got in our 'get it done yesterday' world is the idea that faster is always better or more productive. Nonsense.

Never confuse movement with progress and remember that things that are done slowly tend to be done well and are remembered. It's also worth recalling that the word 'school' comes from

the Greek word *schole*, meaning leisure or leisurely. Learning should be preparation for the whole of life, not just work. Schooling (and I include further education here) should be about understanding oneself rather than understanding where a set of somewhat subjective examination results might lead over the shorter term. Again, it's about taking a whole-of-life perspective.

But, unfortunately, this ancient Greek lesson has been lost. Today, education is tied up almost exclusively with economic utility. In other words, the point of education is largely workforce preparation, although, as we've seen, there's the very real danger that the current system is preparation for a workforce that won't exist in the future.

Some studies (e.g., Frey and Osborne) suggest that a third or more of jobs could vanish over the next few decades due to automation, artificial intelligence and robotics. I think such claims are a little alarmist, but nevertheless it would do no harm to think about whether or not the current system is positively aligned to future developments.

Importantly, are we equipping students with the right attitudes and skills to compete globally—and locally—in a market where value will be derived largely from human interaction and the ability to invent and interpret things that machines cannot?

But the future economy is merely one factor. It is critical that people are given the mental resources to earn a living in a knowledge economy and, perhaps, even within Industry 4.0 and a post-knowledge economy (whatever they may be).

However, the ability to earn a living and buy products should be the by-product, not the primary objective. People should be taught to be more than mere producers and consumers or the managers of machines.

ADVANCE AUSTRALIA FAIR

For me, the purpose of education should first and foremost be the creation of a fair and just society. You might argue that the purpose of education should be employment and that full employment has served Australia well as an output recently, but I think this idea is

failing fast and we should all try harder to come up with something additional that's a little more inspiring for future generations.

Albert Einstein is often quoted as saying that 'Education is what remains when one has forgotten everything one learns in school'. He didn't actually say this at all. He refers to 'a wit' that said: 'Education is that which remains, if one has forgotten everything he learned in school'. The critical word here is 'if' and the point is not the importance of learning anything per se but the act of learning itself. This learning starts at school, but it shouldn't end there.

The role and purpose of education beyond the creation of a fair and just society should be to teach people to think and to think well. This, hopefully, will create and continually reinforce a fair, just and inclusive society. If the prospect of satisfying, meaningful and purposeful work is the preserve of a highly educated elite, then the whole system will eventually fail. We need to demolish disadvantage, not entrench it still further.

But we seem to have forgotten this hugely important lesson. We have forgotten that society means 'we', not 'me', and that true individuality can only exist within the context of an enlightened and liberal whole. We can only truly be ourselves in the presence of others and this includes those who think differently about things. But, unfortunately, education nowadays seems to be increasingly focused on individual attainment regardless of any wider consequences.

In some ways this is a good thing. Individuality and innovation are strongly linked. But innovation only truly flourishes in societies that are diverse and tolerant of other individuals, especially those with seemingly strange or non-conformist ideas. This is why countries like a) Singapore, b) China, c) South Korea and d) Finland all struggle to replicate the radical thinkers that reside in places like California, which, interestingly, isn't dissimilar to Australia in many respects. Both are open to migrants (well, both used to be); both have vast, open, sunny spaces where the imagination can soar; and both regard themselves as young democracies that have escaped the oppression of a colonial past.

In this context, the primary role of education in Australia should be the creation of a common yet flexible culture ('We are one, but we are many … from all the lands on earth we come'). This should be supported by a unifying purpose in which humans and humanity are central, not the economy or technology. But alongside the fetish of the individual we have elevated both business and technology to God-like status when both are mere tools (and you can read that last word any way you like).

Fair and just means that we should be taught to treat each other, and our planet, with respect—and learn not to carelessly exploit either for financial or individual gain.

Whatever you end up doing regarding reform is clearly up to you, but if I were you I would start by exploring purpose in more depth and then move on to what makes humans different to even the smartest machines, because it is within this territory that a sustainable and fulfilling future lies.

In short, how can education contribute to human happiness and fulfilment in the broadest sense, and how can education be applied to ensure that humans work with and not against automation and artificial intelligence?

TEACHING PEOPLE TO BE UNIQUELY HUMAN

To my mind, human creativity and empathy would be at the top of any list of uniquely human characteristics along with the ability to make moral decisions. I would therefore dig deeply into what educational cultures, processes and tools are available to extend and enhance these human traits. In some cases this may mean going backwards—or at least changing a few things—if we wish the world to remain the same.

For example, it's well known that technology companies see the future of education as digital and fully connected. There is big money in this for them. This may well end up being the future, but be very careful not to write off any old ideas simply because they are old or well used. Many things that are very old became so because they're very good.

Thinking of old ideas, don't forget to dig into the history of education too. This would not only provide some further perspective,

but there could be ideas hidden in the attic of education that could be renovated and reintroduced with minimum resistance.

Last year I had an email exchange with an ex headmaster of a respected school in Sydney. He reminded me of the thought propagated by Aristotle and cultivated by Thoreau that society all too often suffers from improved means to unimproved ends. In this context there is a danger that the excessive use of digital technology and connectivity is simply sending us to the wrong destination even faster.

Paper is a case in point. In the rush to digitalise education, we've perhaps forgotten that paper is one of the smartest technologies we've ever invented and one that appears to make people clever. Words slowly written or read on paper tend to be digested better than those written or read on hyperactive screens. As a result, context and argument are seen and understood more clearly on paper. Speed and distraction are inversely proportional to understanding.

A similar point about understanding might be said of downloading lectures and watching them at 1.5 times speed or even potentially of MOOCs. If you live in the middle of the outback, then online learning is better than no learning at all. Used wisely, online learning can enhance and extend other forms of learning. But be careful not to write off the importance of physical teaching and classroom interaction completely. It's difficult to question an online teacher, and good lessons and classroom discussions have a habit of spilling over into the playground or the university bar afterwards in a way that a recorded lecture, often watched alone, cannot.

DIGITAL STARS

It's also difficult to become motivated or inspired by a machine. I know you can offer digital rewards to students, some of which seem to work, but liking a teacher and liking an app are totally different things. At the time of writing, my eldest son is sitting his exams and he has been particularly diligent about revising for geography. Why? Because he really likes his geography teacher and doesn't want to disappoint him. I suspect that in twenty years time

he'll still remember the teacher's name while the apps he used at school will be long forgotten.

Moreover, do not forget that the early years of education in particular are partly about learning to get on with other people. If you remove, or significantly reduce, opportunities for physical interaction among students and staff, it could well be that you are propagating a system in which individuals are taught to ignore, or at least misunderstand, the needs of others.

Remember too the importance of place. I looked into the future of public libraries in New South Wales many years ago and one theme that shone through strongly was that libraries weren't just about borrowing books. Public libraries were neutral, civic, non-commercial spaces in which books, historical objects and, most importantly, people interacted and learnt about each other. They were where people came to learn about things and to find things, including themselves. Schools could borrow an idea or two from public libraries.

The importance of good architecture and design is therefore important, although in the end it is the people and especially the physical interaction between inspiring teachers and willing students with sponge-like minds that's most important.

Another issue—and this circles straight back to not only PISA but to human uniqueness—is that we seem to be worrying more about how well we are doing what we think we must do rather than thinking about what needs to be done. Aristotle, Thoreau and Donald Rumsfeld all rolled into one, if your mind goes back that far.

The Australian system, like most others, seems obsessed with numbers and grades. Progress—or at least attainment—is achieved via standardised testing and one might argue that the passing of exams is the whole point. But are we obsessing about the wrong obsession?

TEACHING TO THE TEST

Exams are how students are evaluated and needless to say the system favours certain subjects, certain intelligences and therefore certain students over others. A model student, as the educationalist

Ken Robinson points out, is one who passes from one educational institution to another with the minimum of friction or fuss.

The system, and it's more or less the system everywhere as far as I can tell, has been designed to test ability across a very narrow range of subjects or skills, often on a particular day—or series of days—come hell or high water. Students take the same tests at roughly the same time (and regardless of age or development) and all other abilities, measures or concerns tend to be diluted or dismissed.

What counts is whether you can regurgitate a series of facts and apply them in a logical manner that is consistent with the views of the examiner or exam board. At its most basic level it's a memory test. At a more sophisticated level (and in later years of education) it's a test of understanding, but rarely do the tests assess anything other than the idea that every problem has a right answer.

None of this was much of a problem when the world tended to be simple and static. But nowadays our problems can be complex, uncertain and ambiguous. Furthermore, many of the world's really big problems are connected. It's like a game of Whack-a-Mole. You hit one problem on the head and another pops up somewhere else.

We should be teaching students about the connected nature of knowledge. We should be giving them the confidence and skills to question conventional wisdom and solve fluid and connected problems—all of which comes back to teaching people how to think for themselves.

We should spend more time asking students to solve real-world problems and especially in groups rather than alone. And perhaps in some instances we should mark the class rather than the individual. This might promote collaboration and encourage the weaker members of any class.

If you've never taken the Spaghetti Tower Marshmallow Challenge, you should, because it teaches everything from physics and negotiation to leadership skills. I'm also keen on goal-based education in the broadest sense. For instance, in addition to teaching science as a subject, science can be taught as the solution to problems such as climate change, water quality or clean energy. In early years this would generally be explanatory and illustrative, but in later years it can actively be about seeking useable solutions.

Again, in the past there wasn't much need to do any of this. If you had an agrarian or factory-based economy on your hands, what you needed were standardised students who emerged from the system into work fully formed and compliant. But if you have an innovation or problem-based economy on your hands, one in which people are paid for either their ideas or their ability to motivate or inspire other people to have ideas, then this system might not be the right one.

This links back to many of the countries towards the top of the PISA rankings. Yes, places like Singapore, China and South Korea perform well when it comes to core subjects like maths, but they score poorly when it comes to producing citizens who can think and act independently.

Excepting its Ivy League universities, the US doesn't instantly spring to mind when it comes to being an educational role model (it was 25th on the PISA rankings last time I looked and is consistently at the bottom in terms of maths). But when it comes to developing world-changing ideas, it is often in a class of its own. This is largely due to a culture of creative criticism and creative destruction. In the US it pays to challenge conventional solutions. This is one upside to individualism, although even in the US there's a limit to what a single individual can achieve working alone.

Contrast this with the likes of China. I've taught classes of executives from China who won't say a word until the most senior executive in the room has spoken, and open criticism is almost unheard of.

How does this sit with the idea that public discussion and criticism are so central to progress? I suppose the trick is achieving some kind of balance between the insight of one and the wisdom of many.

Another issue with the narrow educational focus we have now is that this approach takes no account of the fact that students learn at different speeds and are good at different things. Students tend to be categorised at certain ages (with testing starting as young as five in the UK) and the categorisations can be fairly fixed. In other words, if a child is thought to be a dimwit at the age of eleven, it's

assumed that they'll stay this way forever and this can be reflected in lower standards of teaching. This is clearly a load of old tosh.

It's also rubbish that your whole future can be determined by how you perform on a particular day. Maybe we should mark individuals across their entire school career. Or if you really do want to go down the path of endless examinations, why stop at school? Hey, why not have the government publish annual rankings of individuals from birth to death based upon a series of tests or, more practically, on the opinions of social networks? (Please don't do this.)

A TOLERANCE OF FAILURE

And what of the role of luck? We aren't generally taught about luck at school, or failure for that matter, but both play a significant part in most people's lives. How and why might one integrate luck and failure into national curricula? Life in the broadest and most general sense is about a series of experiments, many of which will result in failure. The trick, it seems to me, is to carry on with a negligible loss of energy or enthusiasm.

This isn't the same as the Silicon Valley mantra that all failure is success, but failure can and does teach us about determination, inventiveness and resilience. As the designer, inventor and billionaire entrepreneur James Dyson puts it: 'Creative breakthroughs always begin with multiple failures … true invention lies in the understanding and overcoming of these failures'. Quite. Schools in particular surely have a responsibility to not only encourage safe and non-judgemental experimentation but ensure that every student has the opportunity to find out through failure what it is that they most enjoy and are best at regardless of peer pressure or subject hierarchies. We need bright chemists and mathematicians, but we also need great farmers and ballet dancers. And, of course, great teachers.

As for luck, it's important to learn that sometimes things don't work through no fault of your own, but equally that luck responds positively to energy and effort. Teaching those that will later do well that luck has played a part also acts as a counterforce to any egotistical urges.

Failure teaches adaptability and resilience, which are possibly two of the most important attributes you can have in a world that's become volatile, uncertain and complex, and is set to become more so in the future.

But let's get back to intelligence.

Defining intelligence in a traditional manner (generally IQ rather than EQ) writes off large numbers of students from an early age. Putting to one side the issue of giving everyone a fair go, I'm constantly talking to employers who despair of graduates with perfect biographies or first-class degrees. High-achieving students are usually technically more able, but they can be more fragile too, never having experienced major failures or frustrations. Their character, personality and selling skills can be sadly lacking too.

The idea of multiple intelligences usually lists eight forms of intelligence, but in education we tend to focus on just one or at best two. We are obsessed with logical and to some extent linguistic intelligence, followed (if you are lucky) by physical and creative intelligence. Social, personal, moral and spiritual intelligence are mostly ignored. This is nonsense. We need to broaden what we value and give students more opportunities to discover what they might be good at. Learning a little bit about everything before you focus on learning everything about something is a lesson we've largely forgotten too. So let's broaden both teaching and student assessment to include a more rounded and societally cohesive set of skills, capabilities and behaviours.

Leaving aside the fact that our narrow focus throws huge numbers of students into a garbage bin at a very early age—and potentially for life—it's dreadfully daft because the intelligences most likely to be made redundant in the face of artificial intelligence and advanced machine learning in the future are logical and linguistic. By contrast, the remaining intelligences, especially social and creative intelligence, are likely to remain the domain of humans, not machines. Go figure.

Creativity (which to my mind includes curiosity, intuition, imagination, originality, aesthetics and divergent thinking) is the intelligence where smart machines are at their very weakest. So too are the nations we seem to be in awe of educationally. But despite

this we seem to be hell-bent on removing the teaching of creative subjects from many curricula to allow for a deeper focus on logical subjects. Illogical. In the UK, for example, half of the schools have axed design and technology examinations so that students can focus on what they consider core subjects, especially STEM.

Putting to one side the thought that art, music and other creative subjects are valuable in themselves because they explain, illuminate and medicate the human condition, there's the question of exactly where our future scientists, technologists, engineers and mathematicians are supposed to get their world-changing originality from if anything remotely resembling an imaginative subject is removed during their formative years. STEM is a short stalk going nowhere if you don't feed it with some imagination.

Another consideration is that, by default, any narrow focus on academic subjects gives certain supposedly intelligent students tacit permission to behave like complete psychopaths at school and later within society at large. If the system doesn't value or measure morality or good character, then it turns a blind eye to people who don't have any and who, quite frankly, shouldn't be let into or out of school in the first place. Under the current system, all that counts is that students pass their exams. What many schools want are kids who achieve high scores, thereby making their own rankings look good. From there, 'successful' students can move seamlessly into a handful of top universities and thereafter into a select group of organisations. At this point their confidence most likely solidifies into arrogance and their brains go to their heads. Have you met any modest CEOs recently?

Physical intelligence (aka sport) looks like it is in reasonably fine fettle in Australia, but we should remain vigilant so that it stays so and resist any attempt to trivialise or dilute its teaching. Childhood (and adulthood) is becoming increasingly sedentary and screen-based and we must flex our muscles to ensure that we all spend as much time outdoors as possible.

We will surely be less inclined to value nature if we spend far less time interacting with it too. A reverence for nature should be taught at an early age and reinforced throughout education. If there's one lesson we don't teach as often as we should, it's that we

only have one world and we should take more care of it. To be fair, this is taught during the primary years, but the lesson is largely lost in later years.

Personally, I'd like to see more schools growing their own food and cooking it too. This isn't domestic science; it's biology, physics and chemistry infused with a hint of sustainability. Come to think of it, you could throw in some geology and astrophysics and perhaps eventually get to God if that's your thing.

I'd also like to see more lessons about the quality of the air we breathe and the pollution we throw into our seas. Indeed, given the number of physical acres devoted to education, I'd like to see more schools aiming to be resource positive or neutral by harvesting their own energy and water (science lessons, design, engineering and perhaps economics).

That's probably enough about sustainability. Much more and the journalists at the *Daily Telegraph* and *Sun-Herald* will create so much hot air that they'll become a renewable energy source. What else might you think about? It's difficult to cover an area as vast as education in Australia in 5000 words, but one other thing I would consider is demographics. This might sound a bit boring, but think of it as being about people again.

The Australian population is ageing and while this has implications for student enrolment a more pressing problem might be teacher recruitment. Too many teachers are set to retire in the near future and you might consider thinking about ways to prevent them from doing so—or at least keeping a little bit of them once they've gone. This in turn links to another people point. Schools are pillars of the local community, but they can be islands of isolation and segregation. Why can't school resources and facilities be more widely used locally? Why do schools have to close when the students have gone home? Why can't older citizens (especially retired teachers) be seen as potential reservoirs to be tapped when other resources dry up? Wisdom can be learnt from older generations and many would be happy to help if only they were asked.

At the other end of the age spectrum, perhaps students could help older people to understand the digital world, and maybe school leavers, and especially university leavers, should be required

to spend time in their own community or, more usefully perhaps, a distant one. If an aim of education is the tolerance and understanding of others, then time away could be highly educational.

Another demographic theme to consider might be the influence of foreign students. I believe that the flow of Asian students into Australian universities is highly significant. Is this a concentration risk? What might happen if this flow dramatically slowed or dried up altogether? But, even if it doesn't, why not design new courses to create new revenue streams for schools and other educational establishments? Evening classes for those aged sixty-five plus looking to re-enter education, for instance?

I think my time and word count are now up, so my final point is this: The thought that the universe will ultimately vanish into darkness can be read in one of two ways. Either—as Alvy Singer says—there is no point to anything, everything we do is ultimately inconsequential, and we should therefore put another shrimp on the barbie and have fun in the sun.

Or you can take the opposite view. That while it shines, the sun illuminates the importance of looking after our tiny planet and every human being briefly attached to its surface. The best way to do this might be to use education to fuel a sense of wonder about the universe and our place within it. To teach people that everyone leaves behind a legacy. Whether that legacy is positive or negative is down to education.

FROM TINY ACORNS: TEN SMALL IDEAS

1. Pay Teachers More (or Make Teaching Tax-free)

Teaching needs to become one of the most desirable professions. I might be wrong, but it strikes me that paying teachers a lot more could dramatically increase the quantity and quality of teachers. If paying more directly won't work, how about making teaching a tax-free profession? Or how about building schools with heavily subsidised or free accommodation on-site for teachers?

2. End the Obsession with Facilities

Schools love physical facilities and IT. They are things you can point to when inspectors and prospective parents come to visit.

And they can be better behaved than students. Buildings, in particular, can be a physical legacy for retiring head teachers too. Both are, of course, important, but not to the exclusion of good teachers (see above).

3. Measure What Matters

End the obsession with exam results and league tables. Or, if you won't, broaden the measure to include other socially desirable factors. For example, could you measure moral character, kindness, dependability or determination? And would someone please start a study looking at the relationships between lifetime achievement (measured in the broadest sense) and schooling.

4. Start and End Things Later

There are two sides to this. On the one hand, open schools earlier and keep them open until later so that parents have more flexibility to drop off and pick up. Kids that come from troubled homes could have more time in a safe environment. The second side to this is why not start schooling when children are older, but the quid pro quo is they leave when they're older too. We've doubled human life spans over the last century, but education still starts around five and ends around sixteen, eighteen or twenty-one. And while we're on the subject of time, why do lessons have to be so rigidly structured? Why can't you have a half-day art lesson, a day of geography or a week of science? Why can't schools be given more flexibility in lesson length?

5. Get Outside More for More Insight

In a country as blessed with good weather as Australia, why are so many kids constantly crammed in classrooms like battery chickens? Get them outside. Interact with nature. Visit other people, other institutions and other communities. This is something the Finnish system does really well.

6. Forbid the Use of Mobile Phones

Wouldn't it be lovely if the internet got switched off on Sundays so that we could recharge ourselves? This isn't going to happen,

but how about banning mobile phones on school premises until the age of sixteen? OMG. This won't go down well with students, but it would remove distraction and could dilute peer pressure and online abuse. The idea would apply to teachers and parents on school premises too.

7. Properly Integrate Schools into Communities

Schools exist within the context of a local community, so why not make more use of this? Invite more people into schools to explain what they do and get more students out into the community to experience everything from policing and health care to local businesses.

8. Make Education More Fun

I'm loathe to say this, largely because some schools have already embraced this with terrible consequences. In fact, fun has emerged as a less taxing alternative to learning in some circumstances because parents don't want their precious little snowflakes doing anything that could be difficult, boring or frustrating. Nevertheless, there's no reason why more humour, wit and outright hilarity can't be injected into everything from education to tax accountancy. Fun is something smart machines will never understand.

9. Don't Shy away from What's Hard and Hard Work

This is my counterbalance to making things fun. Not everything is or can be fun. Learning important stuff is hard and can be mind-achingly boring. Get over it. Learn maths, learn grammar, learn handwriting, learn science (guilty!) even when you don't really have to. It's training the mind for other things that are hard or boring throughout life. Hard is also satisfying. Easy is the path most people take. Hard is less crowded and eventually has a better view. This is something that China, Singapore, Japan and South Korea do get right.

10. Personalise Some Learning Experiences

This contradicts 'we', not 'me', to some extent and there's a danger of reinforcing special snowflake syndrome. Nevertheless, digital

technology affords a great opportunity to tailor some learning experiences. For example, I'm a fan of reading physical books. But physical books are all the same and take no account of the fact that readers can be different. An ebook, by contrast, can read its reader and adjust content or questions according to what it learns about the reader.

CHAPTER 4

Learning to Shape the Future: Reflections on 21st Century Learning

CONNIE K CHUNG

A couple of months ago, on a flight from Boston to San Francisco to visit my family, I sat next to a sixteen-year-old from Hong Kong.[1] Stuck in the middle seat, she struck up a conversation with me and the woman on the other side of her, telling us that she was a self-taught musician returning from a visit to Boston's Berklee College of Music, where she just had been admitted. Her primary mode of music creation was GarageBand, an app on her laptop, and she had just released a record on the global digital music streaming service Spotify. She had the album on her iPhone and offered to play it for us.

I was struck by her musical and technical skills, initiative, friendliness and passion for her work. We spun some ideas about how to get her music more attention. Noting that it had a good beat, I suggested that she get in touch with the talk-show host Ellen DeGeneres and let her know that she had some good dance music Ellen could share with her audience. Our interaction lingered on my mind for days, not just because of her talent and good-natured demeanour, but also because I have been thinking about the

question of what we ought to be teaching in our schools as part of my research about teaching and learning in the 21st century.

My young seatmate's story, to a degree, perfectly captures much of the phenomenon that *New York Times* foreign affairs columnist Thomas L Friedman observed in his 2016 book *Thank You for Being Late: An Optimist's Guide to Thriving in an Age of Accelerations*:

> In 2004, Facebook didn't even exist yet, Twitter was still a sound, the cloud was still in the sky, 4G was a parking space, 'applications' were what you sent to college, LinkedIn was barely known and most people thought it was a prison, Big Data was a good name for a rap star, and Skype, for most people, was a typographical error. All of these technologies blossomed … around 2007.

Humans have been creating and playing music for at least 55 000 years, yet most of the technology that enabled this teenager from Hong Kong to learn and publish music that earned her a place in one of the largest independent colleges of music in the world had not yet been created when she was born. GarageBand was first released in 2004, the iPhone in 2007, and Spotify came into existence in 2008.

Reading Friedman's words in 2017 is a stark reminder of how the technology companies that are now ubiquitous in our lives also only had their start about a decade ago. In describing what some have called the Fourth Industrial Revolution, Friedman analyses the accelerations he sees: an exponential increase in computing power, widespread globalisation and the negative impact of human activity on the environment. He advises individuals and organisations to marshal our values, learn to adapt quickly, and assist those who are in danger of being left behind in such rapid and tectonic shifts.

Friedman is hardly the first to broach this topic. Writing twenty years earlier, the International Commission on Education for the Twenty-first Century issued a report to UNESCO called *Learning: the Treasure Within*. In it, the commission advanced the thesis that education is 'one of the principal means available to foster a deeper

and more harmonious form of human development' and outlined the following challenges associated with the 21st century:

> The coming century, dominated by globalisation, will bring with it enduring tensions to overcome, tensions between the global and the local, the universal and the individual, tradition and modernity, long-term and short-term considerations, competition and equality of opportunity, the unlimited expansion of knowledge and the limited capacity of human beings to assimilate it, and the spiritual and the material.[2]

In such a volatile, uncertain, complex, and ambiguous world, the question of what schools ought to be teaching our young people to navigate and thrive in such a century has been written about and discussed for at least the last 20 years. But the questions about who gets to decide what is learned, the kinds of conditions that enable this kind of learning, and how we can build together the kind of education culture and infrastructure that will be responsive to continually changing needs have not received as much attention.

WHAT ARE 21st CENTURY SKILLS/COMPETENCIES/CAPABILITIES?[3]

Many organisations have devoted resources to answering this question about what constitutes 21st century skills, and these lists can be valuable resources for instigating discussions about what young people need to learn. The National Research Council in the US produced a literature review in 2012 that outlined their answer: essentially, they distilled competencies into three major groups—cognitive, interpersonal and intrapersonal.[4] The Hewlett Foundation has an ongoing discussion about deeper learning; and P21 lists life and career skills, learning and innovation skills, information, media and technology skills, and 21st century themes in their framework. The OECD's Definition and Selection of Competencies (DeSeCo) and the Education 2030 projects seek to define the skills, knowledge, attitudes and values that will help young people shape the future. The Council of Europe has published their thoughts, so too UNESCO, and the list goes on.

Digital literacy or digital intelligence and global citizenship skills are included in these lists, given the opportunities and challenges presented by rapid advancements in technology and globalisation. Digital intelligence is 'the set of social, emotional and cognitive abilities that enable individuals to face the challenges and adapt to the demands of digital life'.[5] Global citizenship education is in part about educating students to understand how connected we are to each other, socially, culturally, economically and politically; to understand both the challenges and opportunities presented by globalisation; and to become positive contributors in such an interdependent world.[6] Other research monographs that look at the kinds of knowledge and skills students need to thrive include financial literacy, health education, environmental education, STEM, wisdom, self-regulation and empathy. In addition, national education ministries, such as Singapore's, have named and incorporated 21st century competencies explicitly into their national curricula.

WHAT MAKES THESE SKILLS PARTICULARLY 21st CENTURY OR NEW?

Of course, there is the question of whether these skills are indeed particularly '21st century' or 'new'. A colleague,[7] looking at the content of a few of the lists of 21st century skills, commented, 'But these skills [such as communication, critical thinking, creativity, collaboration and problem-solving] have been around since [at least] the 4th century BC!' It is true—most of these '21st century skills' have been survival skills used by humans since the dawn of civilisation. But what is unique is that for most of human history, these skills were mostly taught informally, by parents to children, or by master craftsmen to apprentices, or were siloed to specific subject areas, extracurricular activities or subsets of people. The advent of textbook-based mass schooling led to a focus on teaching the three Rs—reading, writing and arithmetic—even though, at least in the US, such a limited focus has been a subject of contention since the three Rs were first proposed.[8]

More recently, with the advent of high-stakes assessments, skills that are 'tested' or 'measured' have tended to be 'treasured' in

classrooms, receiving the most attention. While there are ongoing attempts to assess more complex skills, such as problem-solving, the focus on achieving high test results has inadvertently tended to limit the range of skills that is taught in formal classrooms. Recent research with my colleagues in six countries found that even as the rhetoric in most national curricular frameworks has broadened, these frameworks still focus predominantly, for example, on cognitive competencies rather than on social and emotional competencies.[9]

Thus, it is not that these '21st century skills' are new per se, but the pressing need to teach them to *all* children is new and remains a challenge. The rapid spread of technology makes some skills now more relevant than others in the workplace, and there is a need for ethical, social and emotional skills to navigate a more closely knit and turbulent world. This is also not to say that 21st century skills are difficult to teach or to learn. At the Harvard Graduate School of Education's Global Education Innovation Initiative, for example, we recently compiled a list of fifty organisations around the world teaching these kinds of competencies to children in all regions of the globe, from all backgrounds.

In addition, what is newer is a discussion about integrating both the technical and social aspects of the curriculum. Our problems are equally about the reported increased social disconnection between and among people as they are about the increased dominance of artificial intelligence (AI), perhaps with one phenomenon contributing to the other. Even and especially as technology becomes more ubiquitous in our lives, we may need to be thickening our social capital and our human connections with each other as we monitor and shape the development of AI. For example, recent research highlighted the linked relationship between the rising rates of the opioid epidemic and weaker social capital that has blighted some communities. As is the case for many hotly discussed topics, the solution may not be a choice between 'hard' and 'soft' skills in an 'either/or' fashion, but in a 'both/and' embracing of those competencies.

We might also be wary of inadvertently reducing a conversation about quality teaching and learning in the 21st century to a

narrow discussion about closing 'skills gaps'. Broadening the range of skills we teach in schools is important, but discussions about how we encourage learners to relate well to each other, how adults relate to each other and with learners in ways that strengthen teachers and learners, and how we set up environments that are conducive to modelling and practising not just 'skills' but also healthy relationships, attitudes and values (what scholars sometimes call 'the hidden curriculum'),[10] for example, are equally if not more critically important. We might do well also to think about the kind of infrastructure, resource allocation and learning opportunities that allow all schools to more easily engage all teachers and young people in this kind of learning.

WHAT ARE THE MOST IMPORTANT OR RELEVANT 21st CENTURY SKILLS?

Most of these 21st century skills enable young people to thrive in work and life and act as positive contributing members of their communities. As a lifelong educator, I see the following as broadly important purposes for learning and the competencies that we might want to emphasise:

1. *Passion*, *purpose*[11] and *principles* to guide young people—competencies that help young people develop a strong and secure identity about who they are[12] and what they care about, and develop the kinds of self-knowledge, values and worthy goals that orient them towards building good and meaningful lives for themselves and with others.
2. *Systems* and *long-term and diverse perspectives*, including consideration for other people's points of view and for how the decisions made today can have consequences for other people, social and physical environments, and their lives in the future—competencies that help young people to cultivate the habits of mind that will help them to empathise and think scientifically, strategically, humanely and systematically through the consequences of their actions, and to not strive for glib and easy answers to complex issues. Competencies that would develop in young people the ability to learn to listen to those who disagree

with them, understand them, and even change their minds, based on what they heard; and then be able to communicate why they did so, particularly to those who might disagree.[13]

3. *Participatory*, *problem-solving* and *partnership skills* to contribute meaningfully to their local and global communities—competencies that enable young people not just to become thoughtful consumers and respond to changes, but to become creators who positively shape their work, family and local communities. Competencies that encourage young people to make good judgements about complex issues and to consider the common good when making decisions, to focus on building positive relationships and communities.
4. *Perseverance in pursuing personal growth* that young people would practise and grow in humility, reflection and self-awareness, and be encouraged and equipped to learn throughout their whole lives. Ultimately, they would be curious, nimble and eager learners, seeking to live courageously, confidently, generously and joyfully with others in a complex, changing world.

My seatmate from Hong Kong, for example, clearly had a *passion* for creating and sharing music. Had I been her teacher, I would have loved to have engaged her in conversations about what she saw as her *purpose* in creating music; what she thought about the *ethical principles* of a free music streaming service, and as for the fact that machines were now creating music I would ask her how she might consider the consequences of such technological developments for the future of music creation; how she might consider the *perspectives* of her audience on this topic, in addition to her own; how she might communicate her thoughts similarly or differently in an academic essay, an op-ed and in an interview with Ellen; what she could research about the *public roles* of professional musicians and artists throughout history. I would want to know whether she had thought about ways to create music with others and to share her love of music, perhaps in teaching younger people or offering concerts at public venues; what she was currently curious about; and how she saw herself *pursuing growth and development* for her whole self.

But these are my thoughts of the moment, shaped by my own experiences, research and perspectives. Even more important than coming to an agreement on a list of five, ten, fifty or a 100 key skills, however, is the process of creating the space to conduct inclusive discussions with teachers, parents and students; to be transparent about the reasoning behind why certain skills are included in curricula while others are not; and to encourage key stakeholders, especially young people, to research, discuss and thoughtfully formulate their own informed lists of 'desirable 21st century skills'. This is especially important, as the context we are in is one of constant change, where learning will likely span one's life.

The local context also very much matters in education, even as we live in a globalising world. The answer to the question of which are the most important skills to teach also depends to some degree on the national, political, social, economic and local contexts in which these skills are taught, who is being taught, and for what purpose. Even as we have a degree of consensus about the importance of certain skills like communication, critical thinking or collaboration, how these skills will be taught will vary depending on context. In our study of organisations that have been successful in scaling the teaching of these kinds of 21st century skills to students, we found that successful organisations allowed flexibility for local educators to take their core program and adapt them to local contexts.[14] The Singaporeans have a policy of strategic alignment at the policy level with tactical empowerment at the local level,[15] and British Columbia, Canada, recently revised its curricula by co-creating it with teachers and experts in curriculum design to emphasise core ideas.

Allowing these discussions to lead to a clear, compelling, inspiring and shared vision—whether at the organisational, community, state or national level—is helpful. Most of the organisations we studied had a vision of the kind of future they wanted to see, saw education as a path to get there, and had a theory of change that saw learning as a critical engine for building a good future for individuals and for societies.

If we assume that the ability to take on difficult challenges and to persist in creatively solving them by collaborating with others to

produce high-quality solutions is more important than ever, then focusing on producing students with good test scores or even good skill sets is not enough. In addition to these competencies, we will need to cultivate in young people ways to behave, be and belong with others in the world. Perhaps the most relevant and generative 21st century competencies are ultimately not discrete skills but powerful habits of mind and work that serve people well, no matter what the particular task or challenge.

WHO ARE 21st CENTURY STUDENTS?

If the most important 21st century skills are those that are most relevant to the young people in the particular contexts in which these skills are taught, then it might serve us well to pay as much attention to *who* we are teaching as we do to *what* we are teaching. Sometimes, education systems and stakeholders can care so much about finding the 'right' curriculum that we forget that curricula are being taught in the service of developing whole human beings.[16] Often, we have it quite the other way around, where we are squeezing students into curricula, and where some of the students who do not quite fit what and how we teach are literally being pushed out of the system. They drop out and they 'fail', at least vis-a-vis the existing education system.

Perhaps the lack of discussion we see is due to an assumption that all young people across different generations are the same, or are blank slates waiting to be filled with values, attitudes, skills and competencies. But children enter our schools already having been influenced and shaped by technology and globalisation, among many other factors, and already having been exposed to both opportunities and challenges.

But, of course, these are still general observations, and still not about the person and groups of young people we see in our classes daily. How might we find ways to shape our curricula and reorganise our schools so that learning is relevant to young people's passions and concerns, expanding their perspectives and bringing more discipline to their actions, thoughts and feelings? I do not raise these questions so that teachers can become or replace therapists but because learning is a social, emotional and cognitive

process, and recent research shows how important cultivating healthy relationships with adults is for young people,[17] including the quality of student–teacher relationships.[18]

In addition to providing teachers with more opportunities to learn about learners, young people might be encouraged to learn to drive their own learning, with a focus on reflecting on and learning about their own strengths and weaknesses.[19] Defining 'success' or 'achievement' solely based on the results of tests may leave some with an inflated sense of self and others with a lower sense of self, neither of which provides the full picture of how learners are growing and developing as whole human beings. This is the place where parents, teachers, guidance counsellors and the larger community can discuss, guide and nurture the individuals who are in our classrooms, so that nuances between individuals receive attention while we do not lose sight of providing an equitable education for all students.

WHAT ASSUMPTIONS NEED TO BE OVERTURNED ON THE PATH TO DEVELOPING EFFECTIVE 21st CENTURY LEARNING SYSTEMS?

It may be helpful to articulate more explicitly some of the underlying assumptions about learning and teaching that may need to be overturned in teaching 21st century skills. I list below just three assumptions, but I expect that other assumptions will be uncovered in community discussions with education stakeholders.

Assumption 1) The Future Is Something that Will Happen to Us

Some of the discussions about 21st century skills seem to assume that the future of unchecked domination by forces such as globalisation, technology and environmental disasters is inevitable and that part of the purpose of learning is to teach young people how to defend themselves against such an unavoidable and unknown future. This is certainly a fear- and anxiety-inducing set of assumptions.

Yet as University of Pennsylvania Wharton School Professor Adam Grant, in his book *Originals*, reminds us, 'When we become

curious about the dissatisfying defaults in our world, we begin to recognise that most of them have social origins: rules and systems were created by people. And that awareness gives us the courage to contemplate how we can change them'.[20]

It would be simplistic to say that all aspects of our lives are under our control. However, many aspects of our lives are shaped by our choices. Thus, a key component of 21st century learning would be a kind of education that recognises and develops student agency and choice, as well as equipping young people with the knowledge, skills, values and attitudes to use their empowerment well, so that they can build the kinds of future that would serve them and their communities well.

In addition to formal curricula that help students cognitively understand the role of choice in shaping lives and communities, some schools deliberately organise themselves in such a way that students play key roles in shaping the culture of the school, with opportunities for reflection and action about shared community concerns.

Indeed, young people also have become quite powerful and influential, by their sheer access to information and technology. Many of them are making both small and big positive differences around the world.[21] If we do not want the kind of future that we are powerless to shape and can only respond to, perhaps schools would do better to become spaces where young people are more able to exercise thoughtfully their power and agency, with guided opportunities for reflection, for raising questions, and for shaping their environments and their own growth and learning.

Assumption 2) Teaching Is a Simple Activity and that Changing Curricula Will Change Teaching and Learning

Perhaps part of the reason why so much attention has been paid to discussing and developing curricula for the 21st century is because of an assumption that teaching is a simple matter of delivering curricula. Yet learning is a complex activity, particularly when the emphasis changes to incorporate broader sets of competencies, and it requires attention to be paid to a complex array of cultural, social, emotional and cognitive factors.

If teaching is a complex activity, then changing curricula alone will not impact teaching and learning. For example, how resources such as time are spent matters: how time might be structured during the school day, week, month or year to best allow students to learn more complex skills and undertake more complex projects; how time might be allocated for teachers to learn, implement, reflect, iterate and share new pedagogies with each other; and how much time schools and districts need to implement initiatives effectively.

EL EDUCATION

EL Education is a network of 150 schools in the US that creates the conditions for the kind of learning outlined in many of the documents about 21st century competencies. Built from a collaboration between the Harvard Graduate School of Education and Outward Bound, and funded by a competitive US Government grant more than twenty-five years ago, they have been refining their practice for decades, working with diverse sets of students and schools. EL Education has been recognised for their achievements in traditional fields such as literacy and numeracy as well as in teacher professional development, with one of their teachers being named the US National Teacher of the Year in 2017.[22]

EL Education has identified thirty-eight core practices in five domains (instruction; curriculum; leadership; culture and character; and student-engaged assessment) to address three dimensions of student achievement (mastery of knowledge and skills; character; high-quality work) as part of their work with schools. While these core practices, domains and dimensions are not definitive, what is more important is the discussion, research and practice that led to the agreement in the network of schools and staff that these are the core practices they want to pay attention to for the purposes of improving their work with learners. EL Education leaders expressed that they wished this list was shorter and simpler, but after twenty-five years of running schools, they recognised that the work of operating a quality learning organisation was complex.

EL Education began with a focus on developing curricula, but they quickly realised that curricula that emphasised the teaching and learning of broader sets of skills and learner-centred pedagogy were more easily implemented in association with particular kinds of school cultures, learning networks, relationships with the community, teacher professional development, and policy environments.

Assumption 3) Learning Is a Discrete Activity, over and Done with after the End of a Professional Development Day or after Receiving a Diploma

Given the rapid changes occurring, printing out a curriculum and 'delivering' it for the next eight to ten years will not be sufficient. Learning in the 21st century must be an ongoing rather than discrete activity, and skilled organisations must practise and model this ethos to their students. This held true for the successful learning organisations we studied,[23] where even organisations that were thirty years old were still gathering data and refining their practice, and still learning and innovating.

Rather, it would be helpful to set a broad vision for the purposes of learning, and then create a more dynamic, responsive learning environment that iterates and continually learns as it moves towards achieving an agreed-upon 'vision worth changing to'. This kind of change is not changing for the sake of change every few years, and/or changing with every change in leadership, or because of an attractive idea, but changing because it is necessary to serve the best interests of learners and those who are guiding them.

WHAT KIND OF FOUNDATIONAL FACTORS NEED TO BE IN PLACE TO FOSTER TEACHING AND LEARNING WELL IN THE 21st CENTURY?

Just as there are assumptions that may need to be overturned in teaching and learning well, there may be foundational factors that need to be in place to teach and learn for personal and societal flourishing. Below, I list a few foundational factors to consider.

Foundation 1) A Systems Approach to Education

In an interdependent and complex activity such as learning, it will be important for education stakeholders to learn to think in terms of creating dynamic learning organisations and systems.[24] It is difficult to change just one part of the education apparatus without also paying attention to the other parts. Harvard's Public Education Leadership Project Framework (PELP Framework),[25] for example, outlines key components of school systems that are interdependent. These kinds of frameworks are helpful in encouraging discussion and action among stakeholders about the following kinds of questions: What kinds of learner, organisational and systems-level processes and outcomes are you striving for? What role does each major component of the system play in achieving those desired outcomes? What kinds of roles do learners, parents, teachers, school leaders, policymakers, community leaders and non-profits play in the development and functioning of an effective education ecosystem?

Singapore aims for clear coherence between at least three major components—policy, practice and (teacher and school leader) preparation[26]—which, I have argued elsewhere, is a key factor in its education system's internal coherence and effectiveness.[27]

Thus, a 21st century teaching and learning organisation would do well to think and strategise, and with a focus on systems rather than just on curricula.

Foundation 2) Discuss and Agree to Hold Certain Key Aspects of a Learning System Constant while Agreeing to Iterate Other Components

It may be critically important to discuss explicitly the question of what we will hold constant, even as we make changes to what and how we teach. Counter to the tendency in education to fall in love with the latest good or great idea without discussing purpose, pedagogy, curriculum, teacher preparation, assessment, coherence and alignment with vision and mission, I would urge making space for discussing questions such as: What are we holding constant and what are we changing? What kinds of shifts are required for implementing this new idea well? For what kinds of purposes and

outcomes are we changing? When was the last time we changed something in education, and how does this new change relate to the previous changes?

Determining what education systems are holding constant—whether it is the vision for the organisation or district or other key pieces of the education system—even as other aspects of the system are flexible and iterative, will help to avoid the cycle of constant reforms in education and the accompanying recalcitrant reactions to such seemingly whimsical changes.[28] Effective changes take time, and effective education organisations agree to keep key leaders and partnerships in place, for example, for the time required to implement a new initiative effectively.

Foundation 3) Educating for the Future Necessitates Reflecting about How We Have Taught in the Past

Instead of layering different changes on top of one another, like so many layers of a neapolitan cake, it may be helpful to reflect on how proposed changes relate to existing beliefs and understandings about teaching and learning. For example, the US and other countries my co-author and I studied in our curriculum review for our book *Teaching and Learning for the 21st Century*[29] are emerging from a period of a narrow focus on teaching knowledge and skills that were measured on high-stakes tests. Thus, 'success' in education was defined as having high test scores and entrance to selective colleges.

When we studied programs that were teaching a broader range of competencies for our second book,[30] the leaders of these organisations knew clearly that they needed to reframe what being a 'successful' teacher or organisation meant. For some, it was about developing young people who were not only scoring well on tests, but also were becoming 'good human beings who were deep and thoughtful and have a core of [personal] and citizenship competencies that were contributing to building a better world'.[31] For others, it meant developing students to become more-collaborative group members when working with technology; or it meant developing young people who were creative and caring about other students. The definition of 'success' might have been different across these

organisations, but they had in common the fact that they were able to articulate how their understanding was different from the modus operandi and that, in doing so, they were able to build the infrastructure and content that would enable them to execute and implement their different vision.

CONCLUSION

Teaching and learning is hard work. It is risky, high-stakes work, on which the futures of individuals, organisations, corporations, communities, nations and the planet depend, which may be why there are so many opinions, inputs, so many clarion calls to change, and so much hesitation to do so. It is also the work of nurturing living beings, with their own agency, and doing this work with other people, who also have their own agency.

Thus, education leaders have the task of not only guiding the growth of organisations and individuals, but also the responsibility to create and foster the kinds of climates and conditions in which living beings can thrive. Try to change too much, too quickly, without input and careful attention and listening to the needs, desires and proclivities of these living beings, and teachers and leaders (and parents) can quickly find themselves in a power struggle, including apathy and resistance from the very people they are trying to help. Sometimes, even with the best of intentions and strategies, the substantive fruits of the labour of working with young people will not be seen until months or years later.

Yet teaching is rewarding work, which may be why it is worth the struggle required to create the kinds of spaces in which young people can learn to shape the future.

NOTES

1. Details have been changed to protect privacy.
2. International Commission on Education for the Twenty-first Century (1996). *Learning: the Treasure Within*. UNESCO Publishing, Paris.
3. Depending on the organisation and purpose, 21st century skills may be called skills, competencies or capabilities, among other terms, with organisations arguing thoughtfully about why their chosen terminology and approach is helpful. I think the differences and

rationale are important and worth noting, and that all of them are quite useful, but for the purposes of this essay, which is broadly about skills, competencies and capabilities, I will use these terms interchangeably.

4. Pellegrino, JW and ML Hilton (eds) (2012). *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century*. Committee on Defining Deeper Learning and 21st Century Skills, Center for Education, Division on Behavioral and Social Sciences and Education, National Research Council. The National Academies Press, Washington, DC.
5. Park, Yuhyun (2016). 8 Digital Skills We Must Teach Our Children. World Economic Forum, 13 June. https://www.weforum.org/agenda/2016/06/8-digital-skills-we-must-teach-our-children/
6. I wrote about global citizenship education briefly here: Chung, C (2017). Global Issues and Local Change: Teaching about Power, Possibility, Identity, and Inquiry for Global Competence. Worlds of Education, 3 May. https://worldsofeducation.org/en/woe_homepage/woe_detail/15027/global-issues-and-local-change-teaching-about-power-possibility-identity-and-inquiry-for-global-competence. And I wrote a longer monograph with colleagues in: Reimers, F, V Chopra, C Chung, J Higdon and NB O'Donnell (2016). *Empowering Global Citizens: a World Course*. CreateSpace Independent Publishing Platform.
7. Ashoka India (2010). Aditya Natraj. http://india.ashoka.org/fellow/aditya-natraj
8. I detail some of this history in the chapter co-written with Dr Fernando Reimers in: Reimers, F and C Chung (2016). *Teaching and Learning for the 21st Century: Educational Goals, Policies, and Curricula from Six Nations*. Harvard Education Press, Cambridge.
9. Ibid.
10. See, for example, Anyon, Jean (1980). Education, Ideology, and the Hidden Curriculum. *The Journal of Education*, 162 (1): 67–92.
11. Damon, William (2008). *The Path to Purpose: How Young People Find Their Calling in Life*. Free Press, New York.
12. Suarez-Orozco and others have written about the importance of developing secure identities in the face of globalisation: Suarez-Orozco, Marcelo (ed.) (2007). *Learning in the Global Era: International Perspectives on Globalisation and Education*. University of California Press.
13. See, for example, the International Baccalaureate's work on complexity: Drake, J, R Kupers and R Hipkins (2017). Complexity: a Big Idea for Education? *International School*, 19 (2): 30–33.

14. Chung, C (forthcoming). *Ten Case Studies of Global Organisations that Are Teaching and Learning for the 21st Century*.
15. Ng, Pak Tee (2017). *Learning from Singapore: The Power of Paradoxes*. Routledge, New York.
16. See ASCD's whole child initiative; for example: ASCD (2017). The Whole Child Approach. http://www.ascd.org/whole-child.aspx
17. Search Institute (2017). What Is the 'Relationship Gap' and Why Is It Important? 27 July. http://www.search-institute.org/blog/relationship-gap
18. See, for example, OECD analysis of results from PISA that looks at policies and practices for successful schools: Programme for International Student Assessment (2016). *PISA 2015 Results (Volume II)*. OECD, 6 December; and about students' wellbeing: Programme for International Student Assessment (2017). *PISA 2015 Results (Volume III)*. OECD, 19 April.
19. See, for example: Berger, Ron (2014). *Leaders of Their Own Learning: Transforming Schools through Student-Engaged Assessment*. Jossey-Bass, San Francisco.
20. Grant, A (2016). *Originals: How Non-conformists Move the World*. Viking, New York.
21. See, for example, one profile here: Ashoka (2017). #LeadYoung—Jeroo Billimoria: a Global Movement that Started with a Simple Gesture in Her Teens. 21 May. https://www.ashoka.org/en/story/leadyoung-jeroo-billimoria-global-movement-started-simple-gesture-her-teens. In addition, Design for Change collects stories about young people making a difference in their communities: http://www.dfcworld.com/SITE. And the World Bank collected stories of young people making positive change with technology and social media here: Kumar, Ravi (2013). Social Media and Social Change: How Young People Are Tapping into Technology. The World Bank, 14 January. http://blogs.worldbank.org/youthink/social-media-and-social-change-how-young-people-are-tapping-technology
22. For specific data about their independently documented success, please see: EL Education (2017). Results: by the Numbers. https://eleducation.org/results/by-the-numbers
23. Chung, C (forthcoming). *Ten Case Studies of Global Organisations that Are Teaching and Learning for the 21st Century*.
24. Peter Senge, among others, has written about the importance of systems thinking, particularly for learning organisations: Mutual Responsibility (2012). What Is Systems Thinking? Peter Senge

Explains Systems Thinking Approach and Principles. http://www.mutualresponsibility.org/science/what-is-systems-thinking-peter-senge-explains-systems-thinking-approach-and-principles. Also see his 2006 book *The Fifth Discipline: the Art and Science of the Learning Organisation*, Doubleday, New York.

25. Public Education Leadership Project at Harvard University (2017). Mission & Impact: Coherence Framework. https://pelp.fas.harvard.edu/book/coherence-framework
26. For more elaboration, please see this article written by Sing Kong Lee, former director of the National Institute of Education in Singapore, who kindly introduced me to this idea in the first place: Sing Kong, Lee (2017). Singapore's Education System: Some Key Success Factors. New Zealand Centre for Political Research, 19 March. http://www.nzcpr.com/singapores-education-system-some-key-success-factors/
27. Chung, C (2016). Letter from Singapore—a Systemic and Systematic Approach to Teaching and Learning: Playing the Long Game in Education. Global Education Innovation Initiative, 11 May. https://globaled.gse.harvard.edu/blog/letter-singapore-systemic-and-systamatic-approach-teaching-and-learning-playing-long-game
28. See, for example: Payne, Charles (2008). *So Much Reform, So Little Change: the Persistence of Failure in Urban Schools*. Harvard Education Press, Cambridge.
29. Reimers, F and C Chung (2016). *Teaching and Learning for the 21st Century: Educational Goals, Policies, and Curricula from Six Nations*. Harvard Education Press, Cambridge.
30. Reimers, F and C Chung (forthcoming). *Building Capacity for Teaching and Learning for the 21st Century: Case Studies in Seven Countries*. Harvard Education Press, Cambridge.
31. Interview with EL Education staff.

CHAPTER 5

Educating for a Digital Future: Notes on the Curriculum

MARC TUCKER

In *Educating for a Digital Future: the Challenge*, I described how artificial intelligence (AI), automation, robotics, natural language processing, neural networks and related disciplines have been evolving in recent years, and the implications for work, jobs, the distribution of income and, indeed, what it means to be human. In this brief essay, I explore the implications for what young people might need to know and be able to do to cope with the world I described and perhaps flourish in it, and, in particular, offer some ideas about the kinds of experiences young people might need as they grow up in this new world.

In my last essay, I described the ways in which these technologies are creating a world in which many parts of the jobs that have long been available to young people are disappearing, made unnecessary by machines that can do those parts of those jobs faster, more accurately and less expensively than humans—or simply eliminating the need for those jobs altogether. And I showed how and why these technologies are leading to a world in which a much smaller group of very highly educated and very well trained people

in a small number of fields are in high demand and in a position to do very well in this new environment.

In-between those who simply do not have the education and skills needed to do the work that will be available in the short to medium term, and those whose particular configuration of high education and high skills puts them in a position to command very high compensation even before they graduate from university, is a group who can compete for work that will enable them to earn a good living for themselves and their families, but are most likely to be living in a world of contingent labour, selling their services as independent contractors, in an environment in which advancing technology is reducing the need for the specific skills they are offering and putting a very high premium on their ability to learn new skills very quickly.

Those in the greatest danger now and in the near and intermediate term are those who leave high school with what in the US would be considered a 7th or 8th grade level of literacy in their native language and mathematics. They are particularly well prepared for jobs involving the kind of routine work and modest literacy levels that intelligent machines are increasingly well suited for. I am speaking here of retail clerks, people who drive vehicles for a living, most construction workers, miners, most manufacturing workers, as well as office workers whose work, even though skilled, still involves routines that can easily be captured by an algorithm, such as insurance policy pricing, real estate appraising and middle management jobs that mainly involve data gathering and analysis.

Two points are very important here. The first is that I have just described a very large fraction of the jobs that people do. The second is that in the US and many other industrialised countries, half or more of the young people leaving high school every year have no more than the level of skills needed to do the jobs just described—the very jobs slated for a mass extinction. By mass extinction, I do not mean that these jobs will go away altogether. Many will not be automated, either because important aspects of them will involve skills the machines do not have or because it is less expensive to have a person do them than to employ a machine to do the work. But because there will be many more people who

have low skills than there are jobs available to such people, they will pay very little. What this means is that, in some industrialised countries, the levels to which we are currently educating and training half or more of our high school graduates will condemn them to a lifetime of poverty. I believe the first obligation of education policymakers in the advanced economies in the near term—meaning right now—is to greatly ratchet up the standards for compulsory education to avoid this outcome. This involves, as I will explain in a moment, not just bringing up the lower half to meet the standards now being met currently by those in the middle of the distribution, but changing the kind of education and training we offer all young people.

Educating for a Digital Future: the Challenge then went on to show how the continued evolution of digital technologies could create futures for our children and grandchildren that can plausibly be described as utopian and dystopian. And I pointed out that whether they in fact play out as utopian or dystopian will depend to a great extent on how young people are educated and trained—what kind of values they hold dear; what they think it means to be human and how important it is to them to preserve what is most important about being human; how much they value democracy and what they think it will take to preserve and defend it; whether—as citizens—they understand these new technologies and what it will take to make them forces for good and not evil; to what extent they have the knowledge and skill to fashion a new kind of human society with an economic system that fairly distributes what people need and want, when a great deal of what they now pay for is made in abundance by machines, and a political system that will enable everyone to lead free and fulfilling lives, when the technologies now emerging could just as easily lead to a handful of people reaping most of the rewards of these technologies for themselves and leaving the rest of humanity to lead crabbed and limited lives as 'surplus labour'.

These are immense challenges. Meeting them will require not just a few brilliant minds but an electorate that recognises a demagogue when it sees one, can fully understand the complexities I have just briefly skimmed over and can participate fully in

the transformations human society will have to go through to be successful. It is entirely possible that the most important function of education in the years ahead will be to prepare our future citizens for citizenship in a world only barely imaginable today. I will, in the next few pages, have something to say about this aspect of the education challenge too.

Finally, the obvious. The fates of all of us are intertwined with others all over the world. The temptation in times when incomes are falling and futures are in doubt is to blame others outside our immediate circle, our family, our culture, our religious group, and to shut them out. But isolation is no longer an option. As in so many other respects, we live in two worlds here too. Those of us who are highly educated and doing well are very likely to think of ourselves as bound inextricably to others all over the planet in a web of connections that enrich us in many ways. Those who are facing the abyss, who feel they have no control over their lives, who suspect that their misfortunes are the result of the openness of their society to people who look and talk very differently from them, want to find a way to run the clock back to a time in which they and people they feel close to were respected and prosperous. It is essential that educators find a way to enable all young people to see those from very different backgrounds, in their own backyard and on the other side of the world, as people very like them, with similar aspirations and needs. In a very tightly laced world, empathy is the coin of the realm.

We will begin by focusing on the near to intermediate term. Let's start by getting one thing clear. It will not do to ask, as so many do, what employers need. The world we are in is moving towards a labour market that will be defined by an increasing number of people who will be regarded as surplus labour. That is a world in which employers will want and need a relatively small number of people who will be paid handsomely to invent and manage technologies and companies that lead the digital revolution I have described, a larger group of people who will serve them and provide a wide range of professional and middle skill services, and an even larger group of people, considered surplus labour, who will be given a 'universal basic income' but no work. That is

a world in which educators would be, in effect, asked to decide which children are going to be assigned to each of these three groups because, it will be said, it would make very little sense to invest heavily in the education and training of people who would not be regarded as contributing members of society.

The stand I take is simple. We should never agree to pick the winners and losers in a dystopian world. The obligation of educators should be to prepare everyone to be a strong contributor in the years ahead. If we are successful, they will create a world that does not include a growing number of people who will be regarded as surplus labour, a world in which, as there is less and less work that has to be done, there is more work that is fulfilling than people able to do it. So my frame of reference in thinking about the task ahead is to think about what an education ought to look like if the purpose of that education is to prepare everyone for participation in an economy in which the routine, low-skill work is mainly done by machines and the more complex, more fulfilling work is done by human beings. But the nature of that work is constantly changing, many will be doing more than one job at any given time and they may be very different kinds of jobs, and learning is a constant, built into the daily routine. And finally, for such people, their contribution is defined by the distinctly human, the things that increasingly capable intelligent agents still cannot do: the sudden insight, the warm greeting, the act of kindness, the intuitive grasp of the other person's outlook, the truly creative flourish, the courageous leap, the human bond, the sheer determination, the pride in a job really well done, the creation and development of a team that goes from success to success.

Learning new things very quickly, deeply and well is no mean feat. It is no problem to acquire new knowledge, but it goes in one ear and out the other very quickly unless there are structures of knowledge already in our brain to hang it on—conceptual structures that are essentially explanations of how the world works in that domain, even better when those conceptual structures in our brain are connected to other, related conceptual structures. When all that is in place, the new knowledge fits with something we already know and we can see why it makes sense. When the new

knowledge is integrated with the old, the conceptual structure—the explanation of how the world works—becomes richer, more complex and more powerful and explains even more of how the world works. When we hold up one conceptual structure and then use it to look at a part of our experience for which it was not intended, this new perspective often yields fresh insights that we call creativity. But these conceptual frameworks and the knowledge we gain from them atrophy if they are not used. Every time we use our knowledge to do something important to us, we strengthen the connections, deepen them and build more powerful explanations of how the world works. The knowledge we gain from reading about things is sterile and evanescent if it is not used, especially if it is not used for something that is important to us. Human beings evolved these extraordinary brains in order to survive. So we throw away what we do not use, to make room for the information, knowledge and understanding that we do use.

Every piece of this litany is important as we think about what it is going to take for our students to be successful in the years ahead.

Basic literacy will be absolutely necessary but nowhere near enough. Our students will have to understand the big ideas in the core subjects in the curriculum. They will need to have a deep understanding of the underlying concepts that structure knowledge in those core subjects. They will have to be using those concepts every day to solve complex problems in domains that they find interesting and even compelling. Their curriculum will need to be structured in ways that not only reveal the big ideas in their core courses and demonstrate the power of the underlying conceptual structure to explain a wide range of phenomena in that subject, but they will have to have opportunities to see what happens when the conceptual structure that underlies one subject is held up to another subject.

What I have just described is fundamentally different from a curriculum that is designed to fill a student's head with regurgitatable knowledge and to provide 'coverage' of the subject. In an age in which the internet provides access to an unimaginable bounty of information, the aim cannot be to fill the student's head with information, but rather to provide a sound framework on which

to hang it, as well as the tools needed to sort out facts and sound analysis from clever lies and propaganda.

Schooling for a long time has drawn a line between 'hands on' learning, which has been put in the domain of vocational education, and book learning, which has been the special privilege of the college bound. In my view, this has to end. It is no good to say you have to take this course in order to be able to take the next one. To educate is to explain and to put the tools of learning in the student's hands and head. As I said a moment ago, real learning rarely takes place unless it is used—not ten years from now but today—to solve interesting, real problems. So curriculum designers face a double challenge: to make the courses in the core curriculum much deeper, pointed much more at deep conceptual understanding, and, at the same time, much more applied, much more integrated with doing real things with the knowledge gained, and then, in class, talking about what was learned from the doing.

And you will say, but all that takes time. Where is the time going to come from? And I will say, you have not heard anything yet. I think that primary (what we in the US call elementary) education needs to be much more exploratory and hands-on, and secondary education needs to be much more like the best modern university education in medicine and engineering. Doctors would take courses in pathology and other medical disciplines for years on end before they could put on lab coats, become residents and go on rounds and help out in the hospital. Much the same was true of engineers. Not anymore. Now, teams of doctors in training are brought into the hospital early on, given a carefully chosen presenting case and told to go to work to make a diagnosis. The team members divide up the tasks they need to accomplish to get there, mostly doing research in a variety of domains. They have access to beautifully developed little minicourses in the basics that they can access when they think they need them, and these minicourses point to others that are available. The trainees present their findings and ideas to each other and the others will critique their presentation. Gradually, working together in this way, the team learns how to figure out what might be wrong with the patient and, at the same time, begins to master the material that

would otherwise have been presented in a conventional course. But most importantly, they learn how to learn what they do not know, and you can believe that their professors make sure that they learn how to distinguish research findings they can rely on from research findings that are not so reliable. They are not trained in the expectation that they will know everything they will have to know to be a good doctor. They are trained in the expectation that they have just begun a life of continuing learning, and they have been given the tools to do just that.

On this formulation, the content of the conventional course and the responsibilities of the instructor in that course are transformed. Much of the content is on the web. The key portions of it, however, are deliberately and carefully designed and developed to form the backbone of the curriculum. Teachers are Socratic instructors, asking pointed questions more often than giving the answers.

As I envision this system, it will be crucially important for students to understand and embrace the core values of the Enlightenment, upon which all the progress humanity has made since has been based, especially reasoning from evidence. This applies to physics and history, mathematics and the electronics lab. It is not so because you saw it on the internet or it is here in your textbook. How do you know this is true? Where is the evidence? How can we judge the merits of two policy proposals? Two views of the same historical event? Two proposed treatments for the symptoms this patient is showing? Two interpretations of this novel? Classes can be conducted this way and formal debates can be used for the same purpose. Ask students to take first one side of the debate and then the other, so they are forced to see issues from different points of view. They should be asked to do this kind of research on all kinds of topics and to write papers—at the secondary school level, papers of five to twenty pages—and should get a lot of feedback on what they write. Those comments should focus not just on whether students discovered the relevant facts but on the quality of the analysis, the way the paper synthesises the facts to address the problem the paper posed, the way alternative interpretations of the facts are presented and the degree to which the conclusion is persuasively argued.

The point of the teaching is not to provide basic facts and an opportunity to practise basic algorithms and procedures—all of that is done online—but to build deep understanding, strong thinking skills and the ability to learn and communicate all kinds of things quickly and well. People who have the kind of education I just described will have an edge on intelligent machinery for years to come.

This kind of teaching takes exceptionally good teachers.

But all I have described thus far is coursework. In the world I see ahead, coursework is only part of the curriculum and not always the most important part. I listed above a set of qualities that one can regard as distinctly human, ranging from courage to empathy, from leadership to the capacity to set high goals for oneself and then do whatever is necessary to achieve them. In the world that is coming, people who have these attributes and qualities of character will complement the most capable intelligent machines and will not be sidelined by them. The best schools have always held these qualities in high esteem, but they did not develop them in class. They developed them on the playing field and in their extracurricular activities.

I have seen a high school in Asia that sent its choir to perform at King's College at Cambridge University in Cambridge, England at Christmas, another serving very poor students in a downtrodden community that sent its robotics team halfway around the world to compete in an international robotics competition, and another whose graduates top the scales in international machining competitions. And, of course, countless high schools that send their athletes to regional and national competitions. I've seen high schools in which the school heads have carefully divided the student body into a hierarchy of governing bodies in order to provide not just multiple opportunities for students to participate in student government, but a structure just like that of junior varsity and senior varsity sports to enable students to climb up a ladder of responsibility as they gain more leadership skills. In every case, the students involved are working in teams to achieve almost unattainable goals that require determination, hard work, planning, expertise and teamwork.

And then there are the opportunities that might be available outside the school, in the community. These might range from community service to regulated apprenticeships in firms offering the opportunity to acquire high-level skills of the kind needed to begin well-paying careers right after high school. In some schools, communities and even nations, these kinds of opportunities are mandatory, but in many others they are available simply as options.

In many schools, these activities are available to all, but although it is hoped that all students will participate in something, there is no requirement that they do so. The hope is that students will find something to participate in, but there is no expectation that the student will get anything in particular out of the experience, much less attain a particular level of expertise.

In the world I have in mind, the school would regard the attributes and qualities of character and skills that can be acquired though all of these opportunities as no less important than those that are acquired in class. The school would decide, as a matter of its policy, what skills and attributes they really wanted all students to acquire while in the school and would deliberately create a wide range of opportunities to acquire them—in and out of school, during class and after class. And the faculty would hold itself accountable for making sure not only that those opportunities were available, but that each of them was set to high standards and there was a system for tracking each student as he or she went through school to counsel them on the options, sign them up and track their progress. Such a school would see the classwork and all of these other activities as equally important components of the curriculum, equally worthy of faculty attention and of the faculty's development and assessment time.

In this conception of the school, what is most important is not the school as such or the formal curriculum, but rather the whole skein of learning opportunities that students have as they go through primary and secondary education. The ordered progression of hour-long classes one after another in high school is gone, and in its place is a well-orchestrated set of learning opportunities, constructed from short courses, seminars, projects, clubs, sports and apprenticeships. It becomes the job of the faculty to

design and orchestrate those experiences and to make sure that every student is on a path which, while exposing that student to different experiences, is nonetheless designed to make sure that every single student acquires the full range of cognitive abilities and non-cognitive attributes, especially character and values, that that student will need to cope and prosper in the kind of world I have described. In that scheme of things, what happens outside of class is no longer thought of as an enrichment smorgasbord, but rather as just as essential a part of the curriculum as what goes on in class and just as worthy of careful planning and supervision for each student.

And now I come to the second part of the analysis contained in *Educating for a Digital Future: the Challenge*—the part that posed the very real possibility that our digital future could be one in which a small group of people end up dominating a much larger population who have little to do and few resources to do it with, or just as possible, a world in which the machines take over and, as one wag put it, humans become pets for their machine overlords.

Every advanced industrial nation is now very focused on instruction in the STEM subjects, and with good reason. But I am of the view that our fate as a species may depend as much or more on the teaching of history, politics and comparative studies. As I pointed out in the earlier essay, the advances automation has already made are responsible in no small measure for a neat division in the US between a portion of our population who are among the best educated, most cosmopolitan and wealthiest in the world, and others, more than half, who are literally experiencing a standard of living statistically indistinguishable from that of people living in the world's developing nations. That is fertile ground for demagogues.

Against that background, it is noteworthy that another recent study found that the majority of young people in the US do not think it is very important that the United States continues to be a democracy. There is clearly a connection between these two facts. If democracy has not delivered for a majority of the people, they may not be all that devoted to democracy as a form of government. That may be all the more true because they have no experience

of what it is like to live in a country without the kind of freedom that democracy affords. Thus the very conditions that breed demagogues and autocratic government are the conditions that undermine the commitment to democracy that would enable us to avoid an autocratic future.

A curriculum that includes courses that conceive of history as the story of our country and of the world described as a series of events attached to dates, and of civics as instruction in the mechanics of our form of government, will not address this problem. But history taught as the struggle for democracy and representative government, a story that makes it clear how fragile democracy is and what is needed to keep it alive, is another matter. That history has to be taught warts and all. The story of democracy is a story replete with horrible deeds done by democratic regimes through the ages, but that is true of all regimes, given enough power and enough time. What is crucial here is that students understand that their ability to affect the outcome depends on having a voice and on the protections that true freedom affords for making that voice heard, for making a difference. Unless that happens, a handful of technologists and economically powerful people are more likely than not to reserve most of the benefits of advancing digital technology for themselves and confer most of the costs of that advancement on the rest of us. That process is already underway.

The kind of history I have in mind is history that enables the students to understand how power has been acquired over the years and how it has been used; why, through most of history, government has been run by autocrats to benefit the few, not the many; how the march of science and evidence-based inquiry that has provided the incredible improvements in the human condition that have marked the last few hundred years of history have gone hand in hand with democracy and freely elected government and what could happen if that light were extinguished.

The history we need is history that gives students the tools they need to form their own views on the issues, based on the evidence and on close reasoning. A history of the sort that emphasises the tortuous history of freedom and liberty, that enables students to understand the fundamentals of how the modern global economy

developed and how it works, and that enables students to imagine what the world would be like without any powerful democracies and without the international institutional order created by the world's democracies at the end of World War II—that is the kind of history I have in mind. Without a history of that sort, it is all too easy to see the more dystopian kind of vision of the digital future taking shape in a few short years. It will take the kind of Socratic teaching environment that I mentioned earlier, an environment for learning in which the instructor is constantly demanding to know what you think and why you think it, what your evidence is, where you got it and why you analysed it that way. The student who has learned her history that way is the student least likely to be buffaloed by a demagogic bully and most likely to bring to the fashioning of a new world the best of the lessons drawn from the old one.

But history is not all we need in the core curriculum, apart from the usual suspects of language, mathematics, science and technology.

If I could, I would require every secondary school student to study some part of the world very different from his or her own in a serious way—its people, history, economy, values, religions, literature and music. Growing fear among those who have been greatly damaged first by globalisation and now by automation has led to a growing desire to retreat into isolation and to blame others elsewhere in the world for everything that has gone wrong. But reversing the effects of advancing technology will require more, not less, integration with the rest of the world, because those who do not put up trade and immigration barriers between nations will end up much richer than those who do, and because isolation leads to fear and fear to war. Growing economic suffering will inevitably cause growing conflict among nations, especially since autocrats often rise to power and stay in power by emphasising and exaggerating the threats posed by others outside their own country.

Far more important than teaching other languages, which can only be done with years of instruction, is teaching students to see other, very different people as much more like themselves than they thought likely, and by helping them to understand how others see them, as mediated by their own history, economic situation and

values. Whether the aim is avoiding catastrophic war or enabling trade that benefits all parties, it is essential that the citizens of the advanced industrial countries help their future citizens and workers understand the world from the point of view of people outside their own country. The best way to do that, in my view, is not to study many places superficially, but to study a few places in depth.

Imagine, for a moment, that the world managed to avoid the dystopian future I described and landed, instead, on the broad sunlit plains of a more utopian alternative. Instead of most people living just above the poverty line, people worked just a few hours a week for wages because they had figured out how to get intelligent machines and systems to provide real abundance for virtually everyone. Suppose that humans had developed an economic and political system in which a few winners had not walked away with the whole shebang, but the fruits of the new intelligent machinery were widely shared.

What would we do with our time? Or suppose, as I suggested in my earlier essay, that humans get to the moment of truth, and have to decide whether to merge with the machines—a future forecast by many futurists—or keep them at bay, reserving for ourselves that which is truly human, that part of us we value the most, boxing the machines into roles that enable and serve us instead of inviting them into roles in which we end up serving them.

Whether we enter the age of widely shared abundance, or we get to the point where we have to draw a line in the sand about what we reserve for humans as the machines become ever more intelligent, we would have to decide what is uniquely human and make the most of it. That, in my mind, is where art and music and literature and philosophy come in.

Literature is about the experience of being human. Great literature captures the dilemmas, anxieties, ecstasies and agonies of the human experience and offers centuries of wisdom about life on this planet for our species. The greatest, most universal music and art similarly plumb the depths of our emotional life. The best literature, art and music, at least so far, enable us to lead far more fulfilled lives than we could without them. If our children are able to make it through to an age of abundance in which they are free to

spend their time as they wish, one would hope that we would have opened a door for them to the world's best music, art and literature.

I have been describing an ideal. It would be an ideal for children from the most favoured of families. But today, the majority of children who attend schools in the US live in poverty. To do for them what I have just described is an immense challenge. But to do otherwise is to condemn their children to deepening poverty as the minimum standards for getting and keeping a good job continue to ratchet up. Enabling them to reach the standard of provision I have been describing would require a comprehensive redesign of the public school system for all the children served by it, not just the poor. But nothing less will do.

CHAPTER 6

Preparing Today's Students for Tomorrow's World

MARK SCOTT

THE FUTURE AI WORLD

The challenge facing education systems everywhere is dealing with the pressing daily operational demands of schools, while never losing sight of the dramatically changing world where students will live, work and be active citizens. It is the role of our education system to prepare them to thrive in this world. For educators, the future is not an abstract concept. We can see it in the faces of young people in our classrooms today. Now, more than ever, we need to be planning for their future.

The 300 000 Australian children who began their schooling journey in 2017 will graduate from Year 12 in 2029 and spend most of their working lives in the second half of the 21st century. The predicted pace of technological and societal change makes it difficult to conceive what the workforce they will enter will look like.

Expert opinions about the future of the workforce and society vary. It is clear, however, that even now, automation, robotics and artificial intelligence (AI) are changing workplaces and our lives.

Some experts predict that the changes will be on a similar scale to the Industrial Revolution, dubbing AI 'the new electricity', saying it will have as much impact on society as electricity has over the last 100 years. Electricity has changed every part of our lives in ways that were unfathomable a century ago, and it is predicated that AI will bring a similar technological revolution.

Today's kindergarten children do not know a world in which smartphones did not exist, phones in which AI assistants such as Siri and Google Assistant are commonplace. For this generation, the world is literally at their fingertips—a mere finger swipe away.

The capabilities of machine learning systems and robots are advancing dramatically, changing not just those jobs historically more susceptible to automation, such as manufacturing, but transforming professional occupations as well. In law, for example, AI can undertake research and analysis tasks more commonly performed by entry-level workers. In medicine, AI programs are able to detect cancer in scans more accurately than humans, robots can outperform humans in some keyhole surgeries, and the UK's National Health Service is trialling an AI app Babylon Health to triage patients from home. In time, though to differing extents, this type of technological transformation is expected to occur across all jobs and professions. The speed of this transformation, however, is becoming more difficult to predict.

Predicting how developing technology will impact on society has always been a fraught venture, and experts currently vary greatly in their prognostications about the next few decades.[1] While there is debate about the extent of disruption, there is consensus that there will be widespread disruption to jobs.

Eric Brynjolfsson and Andrew McAfee, authors of the seminal book *The Second Machine Age: Work, Progress and Prosperity in a Time of Brilliant Technologies*, are confident in their predictions that advancing technologies will ultimately bring greater abundance and less drudgery, but they are equally clear that there is no guarantee that everyone will share in the bounty: 'Technological progress is an extraordinarily powerful force, but it's not destiny. It won't lift us into utopia or carry us into an unwanted future. The power to do that rests with us'.[2]

Technological advances underpin economic progress, and the march of history has seen widespread gains from innovation. But we must be alert to the crucial decisions that will affect the impact of technological change on individuals and communities, and especially on those already facing significant disadvantage through lack of education or job opportunities. Technology itself is not a 'natural' force; it is designed, deployed and diffused through a set of public and private decisions. These decisions will need to direct technological advancement on its most positive trajectory, one which helps overcome disadvantage and widely spreads economic and social gains.

While humans may be entirely displaced in some jobs and new jobs will be created, it is predicted that almost all jobs will become to some extent augmented by intelligent technologies. Consequently, the skills required for most jobs will change; many routine aspects of the jobs will become automated, perhaps freeing up workers to concentrate on tasks requiring more social and creative intelligence. Education will be as critical as ever in helping people adapt to rapidly changing workplaces.

Yet, regardless of whether the prognosis of the future workplace leans towards a utopian or dystopian view, experts seem united in the view that it is becoming more difficult to predict the types of skills that people will need to thrive in this technologically augmented future. At the same time, the imperative for education to get this right is perhaps more significant than at any other time in history.

HOW CAN WE BEST PREPARE OUR STUDENTS?

In New South Wales, we are exploring the strategic implications for education of these advancing technologies because education will be the foundation from which to liberate opportunity. We're closely examining what these rapid changes will demand of school education in particular. What does it mean to say that we want today's five-year-olds to leave school thirteen years from now with the depth of knowledge, skills and confidence required to navigate a more complex world?

We are consulting with leaders from industry, business and the education sectors. I've heard much about the challenges they are

grappling with: the impact of rapid technological and economic change in their worlds, the major shifts they are seeing in the workforce, and the changes the tertiary education sector in particular is making to get ahead of the curve. The themes that are starting to emerge from this exploration are both comforting and challenging. It is in part comforting because there is much that is not new. That's good news because the pace of curriculum change is invariably slow.

The fundamentals of education will not change. Literacy and numeracy are, and always will be, the foundations of learning. Despite calls in some sectors that discipline knowledge is redundant in the age of the internet, over and over again I have heard that strong discipline knowledge is essential to deep understanding, strong thinking skills and the ability to learn. It is also just as important today as it ever was for students to understand the core values of the Enlightenment.

But the themes emerging from our explorations present challenges too. We will need to lift expectations and free up space to enable students to delve deeper, to inquire as much as to answer and to apply their knowledge to real-life contexts.

While we cannot predict the future, and the skill requirements of employees of the future, we do know the type of learners that we want to develop through schooling—students who are critical and reflective, open to a lifetime of learning and re-learning, who are comfortable with change and have empathy and a global outlook.

This demands that we all take a broader perspective about what we judge a good education to be, because students with these skills and attributes will likely be best placed to flourish in a world of intelligent machines.

THE SKILLS NEEDED TO THRIVE IN AN AI WORLD

Deep Knowledge for All Students

The conversation around preparing students for the future world must never lose sight of the fundamental importance of the 'three Rs'—reading, writing and arithmetic—recognised by educators the world over. These are the building blocks for higher-order learning, upon which more complex skills are developed.

However, students will need more than just basic skills in these areas. Machines will also have these skills and will easily replace humans in routine tasks. We need to lift the bar higher and ensure that all students are able to reach it. As Dylan Wiliam, Emeritus Professor of Educational Assessment at University College London, has so succinctly put it:

> Our world is becoming more and more complex, and so higher and higher levels of educational achievement will be needed to be in control of one's own life, to understand one's culture, to participate meaningfully in democracy, and to find fulfilling work.[3]

In the age of the internet, information—real and 'fake'—is readily available to all. Students will need to critically analyse and make sense and meaning from the exponentially expanding banks of information available at their fingertips. They will need to move past simply learning facts and develop deep understanding and learn how to meaningfully apply this knowledge. As aptly stated in one discussion with a university vice-chancellor: 'You really have to know something about something to really know anything about anything'. On top of this, critical and creative thinking will need to be developed.

Many NSW schools are already explicitly developing these skills. There are countless examples of schools, such as Woonona High School, that have transformed results through the introduction of a high-expectations culture, a focus on higher-order skills and strong teacher professional development. Many schools, including Rooty Hill High School, are integrating the teaching of creativity and higher-order thinking in every subject.

Students will also need opportunities to develop their skills further by experimenting with ideas, having the room to fail, and solving real problems. This is the way many university courses are moving, and it is what the best of vocational education has always done. Schooling should provide young people with the knowledge they need to approach the future with a dynamic and forward-thinking mindset.

An Understanding of STEM

With the increase in technology, predictions about the skills that students will require in the future almost always highlight the increasing importance of STEM skills. Leaders from industry, business and the education sectors are calling for the need to raise the quality of STEM education in schools and the importance of engaging students with STEM early.

Engaging with Technology

The rapid pace of change means that much of the technology that will exist in the future workplaces of our students has not yet been invented. Many existing technologies will be obsolete in 2030. Students therefore need to be digitally literate and skilled in designing creative solutions to take full advantage of these technologies and utilise them as tools to help improve our lives and learning.

As AI and automation increasingly infiltrate more aspects of our lives, it will be critical that we foster digital skills and that our students are able to engage with the ethical questions that these technologies raise for us all—the privacy implications, issues of transparency and fairness, and the potential for in-built biases in the algorithms that are making automated decisions that affect our lives.

Improving Maths and Science

Scientific and numerical literacy are also of importance to all students. We need to reverse the recent decline in Australia's results in international tests. And we need to broaden the base of people interested in studying maths and science.

The participation of girls, in particular, needs to be more strongly encouraged. In the NSW Year 12 exit exam, the Higher School Certificate, girls account for 36 per cent of enrolments in Mathematics Extension 2 (the most advanced course), 22 per cent of enrolments in Physics, and 6 per cent of enrolments in Engineering Studies. This continues beyond the classroom where in Australia only 16 per cent of STEM-qualified people are female.

Research clearly shows that the self-perception of girls and boys with similar achievement levels and educational outcomes is very different. Girls are generally much less confident in their own ability and potential. Unconscious bias in adults may also perpetuate these divides. This translates into patterns of gender participation that advantages boys' achievement prospects, despite there being no corresponding achievement differences.

Resolving this issue of gender inequality in STEM subjects requires a change of mindset from the very earliest years of schooling; it's clearly not just about the end of high school. The seeds of disengagement with STEM subjects for some students can be found all the way back in primary school and demand systemic solutions. Within our system, schools are making good progress in tackling this divide, with schools such as Gosford High School, Cherrybrook Technology High School and East Hills Girls Technology High School actively encouraging students to engage with STEM, and making these subjects relevant to their students.

Uniquely Human Capabilities

Education has traditionally been a compulsory journey of up to thirteen years of schooling and a few years of tertiary study for those with the opportunity and the desire to undertake it. However, the predicted workplace disruption means that future citizens will need to be more agile in learning new skills to interact with different technology and change careers. They will need to know how, as well as what, to learn. This requires resilience, flexibility and adaptability on a level that has not been seen before.

Students who can embrace learning as a lifelong journey with challenges and failures along the way, who can see these as opportunities for growth rather than obstacles, and see the rewards of hard work, will be well placed to thrive in the coming world. Students will need a growth mindset which allows them to persevere, to have the confidence to take on the unknown, to take intellectual risks and learn from failures.

More than ever, the future demands that our children develop connections with one another, a sense of community, citizenship and collaboration. This will require them to be well informed and

engaged, well educated in ethics and civics, and to have the social and emotional ability to understand and work with people from diverse cultures.

Interpersonal competencies are increasingly the focus of education systems around the globe. Interpersonal intelligence has at its foundation tolerance and respect and incorporates collaboration, teamwork, trust, leadership and responsibility, communication and influence.

It is these skills, along with creativity and complex problem-solving, that will be hardest to instil in machines and will therefore remain the province of human endeavour.

Empathy has been described as a key 21st century competency. Teaching empathy involves considering the complexity of issues in an interconnected worldview. How we develop empathy is a big question for society. The young leaders of today agree. As Belinda Parmar, CEO of The Empathy Business and a Young Global Leader with the World Economic Forum, has noted:

> Our empathy is something that computers will always struggle to emulate. We need to celebrate what makes us different from even the smartest of the machines. While the future belongs to those who are able to navigate this increasingly digitalised world of ours, the choicest spoils will fall to those who can combine technological fluency with emotional intelligence.[4]

VALUING THESE SKILLS

These skills are not new, and many of our schools are already developing them. But the challenge of devoting sufficient time and space to the breadth and depth of education I am describing cannot be underestimated. Nor can we underestimate the challenge of measurement and assessment.

Learning beyond the Classroom

Although school education is traditionally considered to be 'classroom learning', to state the obvious, learning takes place not only in the classroom but outside it and outside of school.

Real-life problem-solving often occurs beyond the classroom, where students practically develop essential skills such as collaboration, goal setting and planning. Consider, for example, the discipline and collaboration built into a sporting team; the creativity that comes from a school play; the critical thinking involved with debating; the empathy that's built into raising funds for Red Cross, and volunteering at a youth group. Clearly our challenge, then, is how to create this wide range of opportunities for all students and how to value them as legitimate experiences for students that are equally worthy of schools' and their teachers' investment.

If what happens outside the classroom is just as important as what goes on in class, how do we carefully plan and track this learning for every student? We need to codify this important learning so we can confidently articulate it and monitor it just as we do with traditional studies of literacy and numeracy.

Diagnosing through Assessment

Assessment is so important in our schools because we must ensure every student is progressing in the acquisition of vital skills.

During my time at the Australian Broadcasting Corporation, audience ratings—the number of people watching or listening to a program—were what was measured. Many other equally important but hard to measure attributes—high-quality and distinctive programming, and uncovering new talent—were not. Consequently, it was hard to convince people that these things mattered as much. So too in schools, where we are very good at assessing numeracy, literacy and content knowledge, but assessments of many of the other important skills, such as resilience and creative problem-solving, are in their infancy. It should not be beyond our wit to measure them.

Internationally, the OECD, UNESCO and others are developing frameworks, standards and assessments for intrapersonal competencies as well as concepts such as 'global skills' to support greater cross-cultural collaboration. Nationally, we have a set of general capabilities in the Australian Curriculum such as critical and creative thinking and intercultural understanding. However, we do not know enough about how some of these skills are acquired,

how to support students to develop them, the most effective teaching practices and the tools and resources schools need to nurture them, and how best to assess their attainment.[5]

It is important that the controversy over high-stakes testing, and the inevitable political debate that swirls around national results, do not distract us from our commitment to putting improved and sophisticated testing tools in the hands of teachers. We need to move away from the single-point-in-time measurement approach to testing, and towards a more dynamic form of assessment that gives teachers flows of insight where progress can be regularly and objectively mapped. This will allow assessment to become more diagnostic, as in medicine, to allow teachers to more easily identify and address individual student needs.

In medicine, we do not look backwards and marvel at the diagnostic tools of fifty years ago; instead, doctors use the new drugs, technologies and proven techniques now available to them. Likewise, in education we should look to technology for how it can help teachers diagnose what students need.

In visiting NSW schools, I see many, such as Curran Public School, that have data walls in which individual students' progress is tracked and where teachers collaborate, like teams of medical specialists might, to address students' needs. At a centralised level, the NSW Department of Education is also using data to more effectively target interventions at schools. Strategies such as Early Action for Success and Bump It Up are targeting schools with the greatest potential to lift literacy and numeracy attainment. This approach is already resulting in performance improvements.

INNOVATION AND INSPIRATION IN THE CLASSROOM

AI could be of great benefit to education, if used wisely. This technology can recognise individual areas of need and find ways to better explain concepts, allowing teachers to make adjustments to lessons and create customised content for specific subjects and students. Already around the world, AI programs are being deployed in online tutoring platforms and collaborative learning environments which can help students connect and collaborate across the globe.

There is a lot of research being undertaken into how AI can improve education. But in order to make the most of the educational opportunities afforded by AI, the education sector needs to shape the agenda. Teachers and school leaders must play a central role in defining a clear purpose for AI in the classroom and students must be involved in decisions about the use of these technologies and educated about the ethical frameworks that accompany their use.

Great teaching will never become obsolete. The challenges that advancing technologies present to education can only be met by exceptional teachers and school leaders. Indeed, in the age of AI, just as now, great teaching will be the most important element. Modelling by the likes of researchers at Oxford University[6] and McKinsey[7] on the susceptibility of jobs to computerisation places the teaching profession as among the least likely to be automatable. That said, the rapid pace of technological change will have implications for our teaching workforce, with new skills required, new knowledge and new ways of working.

We don't want to lose sight of our teachers' greatest strengths—those that are uniquely human—and we need to grow those strengths. The relationships teachers form with students, to inspire them and lead them to greater things, will be more important than ever. We will need to ensure that all our teachers are well supported to adapt to the changing world and that school leaders are equipped to make good local decisions.

Great innovations are already occurring in many NSW schools, including the innovative use of technology, and teachers opening up classrooms, breaking down traditional silos and collaborating across faculties and schools. But while some of this is already happening with positive effect in our classrooms, our immediate challenge is to ensure that we learn from the data and research that is available.

Many international jurisdictions are also looking at these issues. We cannot transplant overseas systems into Australia, but there is much that we can learn from the successes and failures of other systems and the work they are doing.

We need to see which experiments work and to ensure that we are using the latest information to drive performance and investment.

We need to use a more agile approach to innovation within our schools, and not be afraid to trial systematically, evaluate and then try again. Anything less will sell our students short.

TO REAP FUTURE REWARDS, WE NEED TO ACT NOW

The future in the classroom is now. It is on the face of every child our educators teach. We are at a crossroads and we can't sit back and wait for the revolution to happen to us. We need to lead the change. This is education's moment.

Whether today's young people are well prepared to take advantage of tomorrow's opportunities—how well placed today's kindergarten student will be to experience happiness and success in life and work in 2030—will depend on the policies and approaches that we develop now.

There is a real danger that we will be too short term in our thinking, that we will get too caught up with the challenges of today, rather than looking to the future and lifting our sights to the possibilities of tomorrow. We need to pay the price now and accept that although we won't see the impact straight away, the cost is too great to remain with the status quo.

NOTES

1. See, for example: Committee for Economic Development of Australia (2015). *Australia's Future Workforce?* CEDA, Melbourne; Hajkowicz, S, et al. (2016). *Tomorrow's Digitally Enabled Workforce: Megatrends and Scenarios for Jobs and Employment in Australia over the Coming 20 Years*. CSIRO, Brisbane.
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CHAPTER 7

The Implications of Artificial Intelligence for Teachers and Schooling

ROSE LUCKIN

Most people in countries where modern technology is widely used will be interacting with artificial intelligence (AI) through its many practical applications in computers that have visual capabilities, that can learn, solve problems, make plans and understand and produce natural language, both spoken and written. These AI applications are used in areas such as medical diagnosis, language translation, face recognition, autonomous vehicle design and robotics.

AI is also already being applied to educational settings. For example, Alelo has been developing culture and language learning products since 2005 and specialises in experiential digital learning driven by virtual role-play simulations powered by AI.

Carnegie Learning produces software that can support students with their mathematics and Spanish studies. In order to provide individually tailored support for each learner, the software must continually assess each student's progress. The assessment process is underpinned by an AI-enabled computer model of the mental processes that produce successful and near-successful student performance.

UK-based Century Tech has developed a learning platform with input from neuroscientists that tracks students' interactions from every mouse movement and keystroke. Century's AI looks for patterns and correlations in the data from the student, their year group and their school to offer a personalised learning journey for the student. It also provides teachers with a dashboard, giving them a real-time snapshot of the learning status of every child in their class.

These examples merely scratch the surface of what is possible with AI. The purpose of this essay is to explore how AI is relevant to education and what AI can contribute to teaching and learning to help students and educators progress their understanding and knowledge more effectively.

THE RELEVANCE OF AI TO EDUCATION

In order to benefit from the potential advantages of AI—from personalised cancer treatment specified according to individual genetic profiles generated by AI, to workplace automation that increases productivity—we must attend to the needs of education as a matter of urgency.

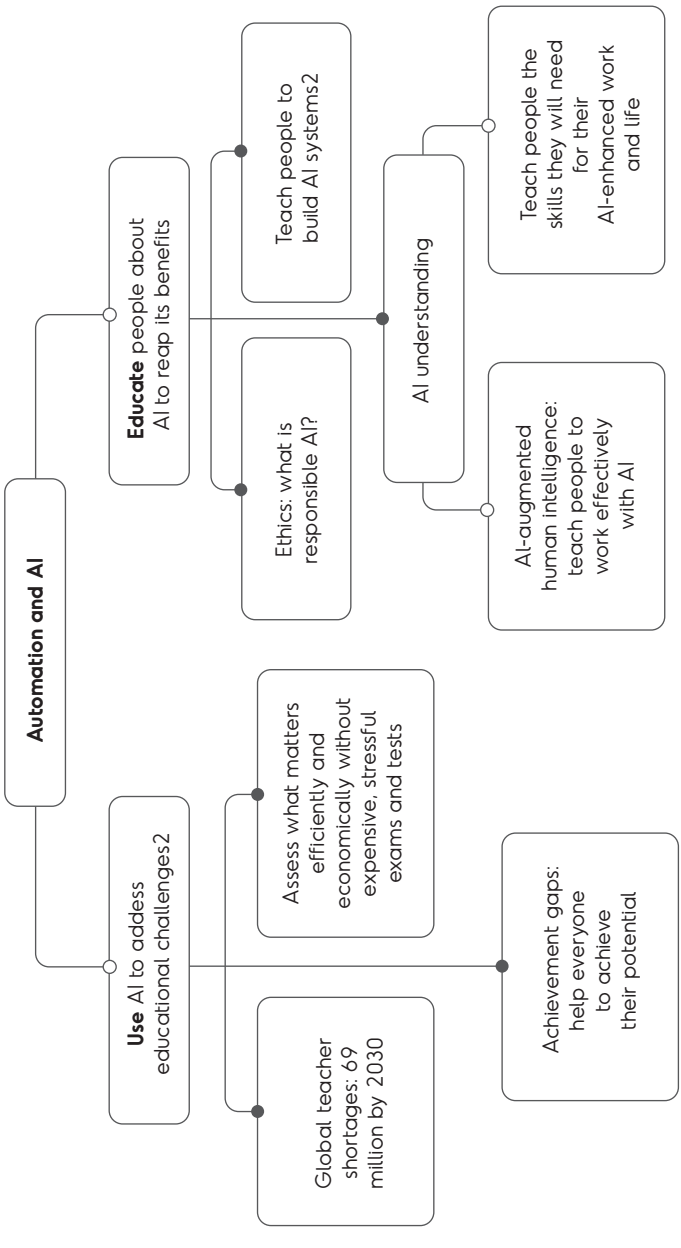
To be blunt, none of the potential AI benefits will be achieved at scale unless we address education and AI now. The nature of what needs to be done is summarised in Figure 7.1, which illustrates the elements involved in the AI and education knowledge tree. There are two key dimensions that need to be addressed:

1. How can AI improve education and help us to address some of the big challenges we face?
2. How do we educate people about AI so that they can benefit from it?

DIMENSION 1: ADDRESSING EDUCATIONAL CHALLENGES WITH AI

The thoughtful design of AI approaches to educational challenges has the potential to provide significant benefits to educators, learners, parents and managers. But it must not start with the technology; it must start with a thorough exploration of the educational problem to be tackled.

Figure 7.1 The AI and Education Knowledge Tree



A clear specification of the problem provides the basis on which a well-designed solution can be developed. Only when a solution design exists can we start to consider what role AI can best play in that solution and what type of AI method, technique or technology should be used. There is an obvious and important role for teachers in the pursuit of a problem specification and solution design. Without this enterprise, the technologists cannot design effective AI solutions to the key educational challenges recognised across the globe.

Identifying the Problem

The *Oxford English Dictionary* defines AI as

> computer systems that have been designed to interact with the world through capabilities (for example, visual perception and speech recognition) and intelligent behaviours (for example, assessing the available information and then taking the most sensible action to achieve a stated goal) that we would think of as essentially human.

AI is an interdisciplinary area of study that includes psychology, philosophy, linguistics, computer science and neuroscience. The study of AI is complex and the disciplines are interlinked as we strive for a greater understanding of human intelligence as well as attempt to build smart computer technology that behaves intelligently.

A key aspect of this definition that is often overlooked is the initial statement about an AI being a computer system that has been *designed to interact with the world* in ways we think of as human and intelligent. In current discussions of AI in the media, for example, we tend to focus on the AI technology rather than the problem and the design process that has informed the implementation of the AI technology. This is ironic, because the most important aspect of AI is the identification of the problem to which intelligence is to be applied and the design of a clear understanding and representation of that problem.

Without this problem specification process, there is no chance of developing a good solution to which AI technology can be applied.

The AI designer must have a good understanding of the problem AI is supposed to solve, as well as the type of AI technique that might be appropriate. The features of the problem must be specified along with the features of the environment in which the AI must operate. Once we recognise the importance of the AI design stage, we can start to unpack the relevance of AI to teaching and learning and the vital role that educators need to play if AI is to meet its potential in the benefits it can provide to education.

I remember when I was an undergraduate studying AI, one of the hardest final year examinations was a paper that we could complete outside normal exam conditions over a three-day period. The paper presented candidates with a selection of problems; for example, a complex of road junctions where fluctuating traffic-flow rates and poor visibility had resulted in a series of accidents, or a teacher who needed to provide support to a class of language-learning students who were all at very different levels of proficiency. As students, we were required to select one of the problems; describe the problem as we understood it, including any assumptions we were making; develop a potential solution; and design the AI techniques and technologies that could be used to implement our proposed solution. The first example problem requires predominantly a planning or possibly a computer vision approach, whereas the second is more likely to be concerned with knowledge collation and representation, and possibly also knowledge elicitation. Students were not required to implement any technology or write any code; the paper was designed to test their design skills.

My point here, then, is that when we ask how AI can contribute to teaching and learning, we need to start from the problems that we believe need to be tackled.

Designing Solutions

Thinking about the problem specification and solution design stage of AI should prompt us to start considering how AI could help us to transform problematic educational activities and bring about changes to the working lives of teachers, changes that would make best use of teachers' uniquely human skills and abilities

and that would remove much of teachers' routine administration, record-keeping and assessment work.

Before looking at examples of the changes that could be made to the job of being a teacher, it is important to consider briefly the changes to the workforce that are likely to occur, partly due to the automation brought about by AI. Schools will need to ensure that they equip students to be effective in the future workforce, and educators will therefore need to know which skills, abilities and knowledge are most valuable for their students to learn.

The impact of technology, particularly automation, on employment is a key topic of debate at the moment in much of the Western world. Predictions about the future pace of technological change due to AI have historically been over-optimistic. In fact, the jobs and skills composition of a workforce have tended to change only gradually over time.[1] The most dramatic historical shift was from agriculture to industry rather than due to an ICT-driven transformation. Current estimates of the impact of future automation on the number of jobs and the types of jobs most at risk vary. See Marc Tucker's essay *Educating for a Digital Future: the Challenge* in this volume for detailed consideration of these issues.

Some jobs are more likely to be augmented by AI rather than replaced through the automation of specific tasks. For example, lawyers routinely conduct document reviews, which is a task that can be automated in some contexts. However, lawyers also provide advice to their clients and complete negotiations for them, and these tasks are much harder to automate. Not only does this suggest that there is not a clear one-to-one relationship between a job lost and a task automated, but also that the coordination of the different tasks between machines and humans may be a new job in its own right. The situation is made more complex by the many factors at play beyond automation, including globalisation, environmental sustainability, urbanisation, increasing inequality and political uncertainty.

The only thing we can be sure about is that the future workplace will be uncertain and unpredictable, and that our students will therefore need to be able to cope with this uncertainty, to be resilient, flexible and lifelong learners. The way to achieve this is to

focus on individuals as learners and enable them to be effective for themselves and with and for others and society too.

The key skill people will need for their future work lives will be self-efficacy. By this I mean that every individual needs to have an evidence-based and accurate belief in their ability to succeed in specific situations and to accomplish tasks both alone and with others. A person's sense of self-efficacy plays a key role in how people tackle tasks and challenges, and how they set their goals, both as individuals and as collaborators. It is something that can be taught and mentored and it requires an extremely good knowledge of what one does and does not know, what one is and is not so good at, where one needs help and how to get this help. This self-knowledge is not just about subject-specific knowledge and understanding but also about one's wellbeing, emotional strength and intelligence.

This self-knowledge and efficacy is particularly important because these are skills that AI cannot replicate. No AI developed to date understands itself; no AI has the human capability for metacognitive awareness. We must therefore ensure that we develop our knowledge and skills to take advantage of what is uniquely human and use AI wisely to do what it does best: the routine cognitive and mechanical skills that we have spent decades instilling in learners and testing in order to award qualifications.

The implications of this for school systems, the curriculum and teaching are profound, and educators must engage in discussing what needs to change as a matter of urgency. This is not a job for the technologists, but if we do not motivate educators to engage in discussions about what AI could and should be used for in education, the large technology companies may usurp the educators and occupy the AI vacuum that a lack of engagement will produce.

Leveraging AI to Enhance Teaching and Learning

What should be clear from the discussion about the future of the workforce is that we need to review what and how we teach and ensure that AI is designed and used as a tool to make our students (and ourselves) smarter, not as a technology that takes over human roles and dumbs us down. To achieve this, we need

to concentrate on developing teaching and schooling that develops the uniquely human abilities of our students and instils within them the requisite subject knowledge in a flexible, interdisciplinary and accessible manner.

The parallel in teaching is that we need AI assistants to relieve teachers of the routine automatable parts of their job. This will enable them to focus on the human communication, the sensitive scaffolding, and supporting the wellbeing of their students so that they can build the self-knowledge and self-efficacy that will ensure that they are able to advance in their chosen workplace.

Three examples of the ways in which teaching and schooling could be reimagined are presented below. Each is driven by a significant educational challenge.

Example 1: Assessing What Can't Be Automated, Not What We Can Easily Automate

The current outdated assessment systems that prevail across the world revolve around testing and examining the routine cognitive subject knowledge that can easily be automated. These assessment systems are ineffective, time-consuming and a cause of great anxiety for learners, parents and teachers. However, there is now an alternative due to the potential information we can gain from combining big data and AI and applying it to the problem of assessing learning. There is a rather beautiful irony in the fact that, while unable to understand itself or develop any self-knowledge, AI can help us to understand ourselves as learners, teachers and workers.

By this I mean the following:

- The careful collection, collation and analysis of the data that can be harvested through people's use of technology gives us a rich source of evidence about how learners are progressing: cognitively, metacognitively and emotionally.
- Continuing work in psychology, neuroscience and education has increased our understanding of how humans learn. This increased knowledge can be used to specify signifiers or behaviours that evidence learner progress.

- Our increased knowledge about human learning can also be used to design AI algorithms and models that can analyse data about learners, recognise signifiers of learning and build dynamic models of each individual student's progress holistically, so that we can chart their development of self-knowledge and self-efficacy as well as their increased knowledge and understanding of key subject material.
- The final step in the process is to design ways in which we can visualise the data that has been analysed to define each learner's progress cognitively, metacognitively and emotionally. These visualisations can be used by learners, educators and parents to understand the detailed needs of each learner and to develop within them the skills and abilities that will enable them to be effective learners throughout their lives.

An AI assessment system that was composed of these AI tools and that illustrated to every learner the analysis of their progress in an accessible format would support learning and teaching by continually assessing learning of both subject knowledge and the skills and capabilities that the AI-augmented workforce will require, such as negotiation, communication and collaborative problem-solving.

This AI assessment system would be more accurate and cheaper than the human-intensive examination systems currently in place and it would free up time for teaching and learning that is currently taken up when we stop teaching in order for people to sit tests and exams. Assessment would happen continuously while people learn. This assessment change requires political will as well as investment in technology development and engagement with teachers, students and parents so that they fully understand the AI assessment proposition.[2]

Example 2: Addressing the Achievement Gap between Advantaged and Disadvantaged Learners

AI could help to make the education system more equitable. Education is the key to changing people's lives, but the less able and poorer students in society are generally least well served by education systems. Wealthier families can afford to pay for the coaching

and tutoring that can help students access the best schools and pass those currently cherished exams.

AI would provide a fairer assessment system that would evaluate students across a longer period of time and from an evidence-based, value-added perspective. It would not be possible for students to be coached specifically for an AI assessment, because the assessment would be happening in the background, over time, without necessarily being obvious to the student. AI assessment systems would, for example, be able to demonstrate how a student deals with challenging subject matter, how they persevere and how quickly they learn when given appropriate support.

One of the key benefits that AI can bring to all learners is the capability to understand more about themselves: what they know and where they need help to understand, their strengths and weaknesses and their wellbeing. Metacognitive awareness is a complex concept, but broadly it refers to any knowledge or cognitive process that references, monitors or controls any aspect of cognition. Scholars distinguish between a person's knowledge of their cognitive processes and the processes they use to monitor and regulate their cognition. This latter regulatory process incorporates a variety of executive functions and strategies, such as planning, resource allocation, monitoring, checking, and error detection and correction.

Good metacognitive awareness and regulation enhances cognitive performance, including attention, problem-solving and intelligence, and it has been shown to increase learning outcomes.[3] Successful students continually evaluate, plan and regulate their progress, which makes them aware of their own learning and promotes deep-level processing. Metacognitive awareness and regulation can be taught and supported, and can benefit learners of all abilities.

A series of studies we conducted using an AI software simulation called the Ecolab demonstrated that AI could be employed to scaffold learners to develop metacognitive skills, in particular help-seeking and task difficulty selection skills.[4] The Ecolab software provides simulation activities for children aged eight to ten years to help them understand food chains and webs.

Children build a simulated world of animals and plants and then solve increasingly complex activities with personalised, artificially intelligent assistance from the Ecolab. In particular, the later versions of the software helped children develop their metacognitive skills as well as their knowledge of food chains and webs. The results demonstrated that the students whose subject knowledge and ability had been assessed as being below average gained particular benefit and performed significantly better than more-able students, who also performed well.

In addition to employing AI to scaffold the development of these important learning skills, we can also use AI to help students visualise the trajectory of their progress and increase their self-awareness. Such visualisations can map the level of difficulty of the work that the student has completed on specific curriculum areas and how much help the child has received.

Example 3: Making Teaching More Effective

One of the big problems that we need to address in education is the global shortage of teachers. The temptation when faced with such a problem is to consider AI as a potential solution through its provision, rather than that of human teachers. There are, however, at least two significant reasons why this suggestion reflects a poor understanding of the problem. The full spectrum of skills and abilities required of teachers is broad and complex. So while AI tutors may be able to provide tutoring in particular subject areas, AI is not (yet) able to fulfil the entire role of a human teacher. A much more feasible approach would be to augment human teachers with AI assistants in the classroom, to help the teachers cope more effectively with their classes of students.[5]

Imagine a classroom setting ten years hence where data about each learner's movements, speech and facial expressions is automatically logged by passive capture devices within the fabric of the classroom. This information is combined with data about each learner's performance recorded by the school's assessment system and the teacher, parents and learner themselves. All this data is used to update the class teacher's pupil records and to provide data for

an AI-based teaching assistant that keeps track of every learner's cognitive, emotional and metacognitive progress.

The AI teaching assistant relieves the teacher of all record-keeping and recording activities and is able to provide up-to-the-minute information about any pupil through a teacher-activated, speech-based interface or a software application. Teachers can also ask their AI assistant to identify an appropriate tutoring application for a group of students who need particular support with an area of the curriculum. The AI assistant can search for resources or media to meet the teacher's requirements for the day, or it can identify and contact local entrepreneurs who are willing to come and talk to pupils about future work opportunities or how to be an entrepreneur.

The possibilities for the AI assistant are vast and encompass all the routine, data-intensive and time-consuming activities that are essential to the smooth running of the classroom, but that don't need the expertise of a teacher. This allows the teacher to focus on the process of teaching and learning, ensuring that all pupils benefit from the unique human skills involved in effective intersubjective teaching and learning interactions.

There are more than thirty years of research on AI for education that demonstrate that we can use AI to make teaching more effective and more economical by augmenting teachers with AI systems so that they can concentrate on the teaching activities that require the general and specialist intelligence that AI does not (yet?) have. The outputs from this research are now required to build the AI teaching assistants that schools and universities need. We have the technology know-how; we now need the initiative to make such assistants a reality. This initiative would need to engage educators across the sectors to help ensure that the capabilities of AI assistants address the requirements of their teaching realities.

DIMENSION 2: EDUCATION ABOUT AI

There are three key elements that need to be introduced into the curriculum at different stages of education, from the early years through to adult education and beyond, if we are to prepare people to gain the greatest benefit from AI.

The first is that everyone needs to understand enough about AI to be able to work with AI systems effectively so that AI and human intelligence (HI) augment each other and we benefit from a symbiotic relationship between the two. For example, people need to understand that AI is as much about the specification of a particular problem and the careful design of a solution as it is about the selection of particular AI methods and technologies to use as part of that problem's solution.

The second key element is that everyone needs to be involved in a discussion about what AI should and should not be designed to do. Some people need to be trained to tackle the ethics of AI in depth and help decision-makers to make appropriate decisions about how AI is going to impact on the world. If we ignore the need for education about AI, then we risk failing to empower people to make key decisions about what it should and should not, could and could not, will and will not be able to do for society.

Third, some people also need to know enough about AI to build the next generation of AI systems.

In addition to the AI-specific skills, knowledge and understanding that needs to be integrated into education in schools, colleges, universities and the workplace, there are several other important skills that will be of value in the AI-augmented workplace. These skills are a subset of those that are often referred to as 21st century skills, and they will enable an individual to be an effective lifelong learner and to collaborate to solve problems with both artificial and human intelligences.

This includes the importance of both metacognition and self-efficacy, referred to earlier, which are interlinked and essential for lifelong learning. We risk failing to sufficiently recognise the importance of these concepts because we are only measuring subject knowledge.

Similarly, collaborative problem-solving brings together thinking about the separate topics of collaboration and problem-solving, each with their own research history. Collaborative problem-solving is a key skill for the workplace and its importance is only likely to grow as further automation takes effect. But there is a mismatch between the substantial evidence in favour of collaborative problem-solving

and learning reported in the literature, and the approaches widely used within schools.

Many current approaches are neither preparing students for university nor the workplace. For example, in an interview for a Davos 2016 debate on the future of education, a student from Hong Kong stated that the current school system produced 'industrialised mass-produced exam geniuses who excel in examinations' but who are 'easily shattered when they face challenges'. We need employees to be able to tackle challenges and this often involves working effectively with others to solve the problem at the heart of any challenge; we don't need exam geniuses who crumble under the pressure of the real world.

Collaborative problem-solving does not happen spontaneously. Both teachers and students require a high level of training to employ collaborative problem-solving effectively, and yet there is little evidence of a concerted training effort. This means that when teachers do attempt to employ collaborative problem-solving, the quality of the group interactions and dialogue can be poor.

While it is difficult to isolate the precise nature of the key factors that impact on the effectiveness, or not, of collaborative problem-solving, we can identify factors that are frequently mentioned as influencing success. These factors include the environment in which collaborative problem-solving takes place; the composition, stability and size of the group and their problem-solving and social skills; and teacher training.

To be effective at collaborative problem-solving, people need to be able to:

1. articulate, clarify and explain their thinking
2. restructure, clarify and in the process strengthen their own understanding and ideas to develop their awareness of what they know and what they do not know
3. adjust their explanations when presenting their thinking, which requires that they can also estimate others' understanding
4. listen to ideas and explanations from others—this may lead listeners to develop understanding in areas that are missing from their own knowledge

5. elaborate and internalise their new understanding as they process the ideas they hear about from others
6. actively engage in the construction of ideas and thinking as part of the co-construction of understandings and solutions
7. resolve conflicts and respond to challenges by providing complex explanations, counterevidence and counterarguments
8. search for new information to resolve the internal cognitive conflict that arises from discrepancies in the conceptual understanding of others.

IMPLICATIONS FOR TEACHER TRAINING AND PROFESSIONAL DEVELOPMENT

The significant educational implications that AI brings to society, both when it is viewed as a tool to enhance teaching and learning and when it is viewed as a subject that must be addressed in the curriculum, make clear that teacher training and teacher professional development must be reviewed and updated.

If teachers are to prepare young people for the new world of work, and if they are to prime and excite young people to engage with careers designing and building our future AI ecosystems, then someone must train the teachers and trainers and prepare them for their future workplace and its students' needs. This is a role for policymakers in collaboration with the organisations who govern and manage the different teacher development systems and training protocols across countries. If the need for young people to be equipped with knowledge about AI is urgent, then the need for educators to be similarly equipped is critical and imperative.

On a more positive note, the development of AI teaching assistants will provide an opportunity for developing deeper teaching skills and enriching the teaching profession. This deepening of teacher expertise might be at the subject knowledge level, or it could be concerned with developing the requisite skills to support and nurture collaborative problem-solving in our students. It could also result in teachers developing the data science and learning science skills that enable them to gain greater insights from the increasingly available array of data about students' learning.

Any failure to recognise and address the urgent and critical teaching and training requirements precipitated by the advancement and growth of AI is likely to result in a failure to galvanise the prosperity that should accompany the AI revolution.

CONCLUSIONS: THE IMPLICATIONS OF AI FOR EDUCATION

It is clear that we need to see AI as more than particular technologies, such as machine learning, neural networks or deep learning algorithms. For education to benefit from the potential of AI, we must focus on the problem specification and solution design elements of AI. We need to develop a culture of problem specification that encourages people to unpack educational problems, so that solutions that benefit from the symbiosis of AI and human intelligence can be developed.

We need to start developing a curriculum and a pedagogy to ensure that our students develop the self-efficacy that will set them apart from their AI peers and that will help them to deal effectively with the changing and perhaps turbulent workplace of the future.

We need to consider the great scope that the development of AI-augmented teaching practices provides to reimagine teaching and schooling. This means that educators must ensure that their voices are heard by the technology companies that are developing their particular technology classrooms of the future. Early progress might easily address the administrative and routine tasks that currently take too much teacher time.

In addition, there are social, technical and political challenges that require our attention. Socially, we need to engage teachers, learners, parents and other education stakeholders to work with scientists and policymakers to develop the ethical framework within which AI assessment can thrive and bring benefit. Technically, we need to build international collaborations between academic and commercial enterprises to develop the scaled-up AI assessment systems that can deliver a new generation of exam-free assessment. Politically, we need leaders to recognise the possibilities that AI can bring to drive forward much-needed educational transformation within tightening budgetary constraints. Initiatives on these three

fronts will require combined support, including financial, from governments and private enterprise.

AI has the potential to bring about enormous beneficial change in education, but only if we use our human intelligence to design the best solutions to the most pressing educational problems.

NOTES

1. Handel, MJ (2012). *Trends in Job Skill Demands in OECD Countries*. Working Paper No. 143, OECD.
2. For a more detailed account of this argument for AI assessment, see: Luckin, R (2017). Towards Artificial Intelligence–Based Assessment Systems. *Nature*, 1 March.
3. See, for example: Marzano, RJ (1988). *Dimensions of Thinking: a Framework for Curriculum and Instruction*. The Association for Supervision and Curriculum Development, Alexandria, VA.
4. Luckin, R and B du Boulay (2016). Reflections on the Ecolab and the Zone of Proximal Development. *International Journal of Artificial Intelligence in Education*, 26 (1): 416–30.
5. Luckin, R and W Holmes (2017). A.I. Is the New T.A. in the Classroom. How We Get to Next, 5 January. https://howwegettonext.com/a-i-is-the-new-t-a-in-the-classroom-dedbe5b99e9e

CHAPTER 8

A Conversation about Computational Thinking

JEANNETTE M WING

The following is an edited conversation about computational thinking with Jeannette Wing.

What is computational thinking and why does it matter?
I define computational thinking as the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer—human or machine—can effectively carry it out.[1]

I believe that the skills one learns as a computer scientist are incredibly important for anyone working in any job in today's society. It does not matter what field you study, what profession you pursue, or even in what sector you practise. I see this need in spades in industry. I'm also seeing that many colleges and universities around the world have embraced this belief and realised that the job opportunities for their graduates demand computational thinking. It's more than programming skills that employers are asking of their employees. Ten years ago it might have been a harder

argument to make, but now it's a given. Anyone who graduates knowing computational thinking or with the skills of a computer scientist will have an advantage over those who don't and they will be more competitive in the job market.

Computational thinking is sometimes equated with coding or programming. How can the 'computational thinking = programming' trap be avoided?
Computational thinking is more conceptual than programming. In my definition, I deliberately use the terms 'thought processes' for formulating a problem and expressing a solution—it's what you do in your head. Programming is a way to make the solution concrete so that it can be run on a computer that is a physical machine. So computational thinking first and foremost is what humans do. Programming is an expression of a solution that a machine can understand. Of course, when you are programming you are using computational thinking, but the opposite is not true: you can be doing computational thinking and not be programming at all.

You have promoted computational thinking for over a decade now. Are you surprised at how influential computational thinking has become in education?
I'm not surprised it has become influential in higher education. When I was at the National Science Foundation ten years ago, I helped create a program called Cyber Enabled Discovery and Innovation. It was all about computational thinking for scientists and engineers. So even ten years ago, it was already a given that computing was going to be necessary for conducting research in any science and engineering field. This recognition meant that graduate students were going to have to learn computational thinking regardless of what field they studied. Also, ten years ago, for undergraduates I was promoting the idea that introductory computer science courses should focus more on the higher-level concepts of computer science rather than focus primarily on learning a particular programming language or only learning how to write code. That idea was already in the air so I'm not surprised

that computational thinking has taken over at the undergraduate level. Now such courses are the most popular on many campuses.

I am surprised at the pace at which we have made inroads at the K-12 level. I need to thank the advisory committee I had while I was at the National Science Foundation for encouraging me to look at K-12, especially early grade levels. While I was promoting computational thinking across the foundation, the advisory committee asked, 'Why don't you tackle K-12?', and I said, 'You've got to be kidding! I know nothing about K-12 education'. Moreover, in the US, doing anything in the K-12 space is a huge undertaking. One reason is that K-12 is extremely decentralised in the US. There are 10 000 school districts and to effect any kind of national change you have to go to each district one by one. I didn't fathom tackling that challenge! However, being at the National Science Foundation, I did have a national platform; moreover, the foundation has a directorate focused on education. Thus, I was able to leverage my position at the National Science Foundation in ways that did move the needle.

Specifically, the lever we used was advanced placement courses, which are college-level courses taken by high school students in order to get college credit. We worked with the Educational Testing Service and the academic community to create a new advanced placement course in computer science. We started to promote this new course as one which high schools should offer—in addition to the existing course, which was primarily focused on programming. At the same time, colleges and universities were changing their first-year and introductory computer science courses. By ensuring that the curriculum of the new advanced placement course matched the new college-level curricula, we could effect a change across K-12 in the US in a scalable way. It was an alignment of stars and perfect timing. Exploiting this lever made a dramatic difference above and below.

But to be honest, the real credit for a lot of what was happening at the K-12 level is due to the entire computing community working with educators, especially teachers in high school and elementary school, and even with the Department of Education.

Meanwhile, computing technology continued to pervade our everyday lives. Young children took technology for granted and were growing up more tech-savvy than their parents. People recognised the importance of having K-12 students learn computing skills. At the same time, companies in the IT industry, such as Microsoft, Facebook, Google, Apple and so on, were desperately trying to hire people with computing skills. The demand far outweighed the supply. These companies realised they needed to look one level earlier in the pipeline and to encourage more students to take computer science in high school. The huge demand for talent by industry helped drive the awareness of computer science education at the K-12 level.

When I first started talking about computer science at the K-12 level, I said that there are two very fundamental questions that need further research by the education community. The first is, what are the concepts to teach and when? My analogy is mathematics, where we figured out that by the time you are five years old you have enough mathematical sophistication to understand numbers and relations, such as greater than and less than; by the time you are twelve years old, you have the mathematical sophistication to learn algebra; and by the time you are eighteen years old, you have the mathematical sophistication to learn calculus. Somehow we have learned from teaching mathematics for centuries and studying mathematics education both how the brain develops and gains the sophistication to do mathematical reasoning, and how can we align the teaching of mathematical concepts to that growth in reasoning capability.

So, ten years ago, my question to the computer science community working with educators was 'What is the analogy in computer science?'. This question had never been asked before. I strongly believe it's important to do research to figure this out. In the beginning, I was pretty adamant that we should understand the science underlying how to teach computer science to young children—to do the research—before we go out and invent a lot of curricula that are not grounded in science. But there was so much momentum around me that people just went out and

started inventing curricula. Fortunately, the education community is pursuing this line of research now. Also, new technology, such as massive online learning, enables us to do large-scale experimentation as part of the needed research in education.

There definitely is a lot we don't know that will take time to figure out. Analogously, we still have what we call in the US 'maths wars', where we continue to tinker with teaching mathematics in K-12. I anticipate that, decades from now, we will still be trying to figure out how best to teach computer science to K-12 students.

The UK, through their Computing At School initiative, has introduced computing at all levels. It is a very courageous effort. The UK is my exemplar. I hope countries around the globe look to the UK as a leader and learn from them as they push the frontiers of education in computer science.

The second fundamental question is how best and when should we use 'the computer' in the classroom to teach and reinforce computational thinking concepts? Here my concern is throwing technology into the classroom and thinking the students are going to learn anything, let alone computing. We need further research on how computing technology can be used effectively for learning and not hinder the learning process. We also need research on how such technology can help reinforce the learning of computational thinking specifically.

Some commentators have argued that computational thinking mainly benefits students in statistical or scientific environments, and that the benefits of computational thinking in other disciplines such as creative arts or humanities have not been empirically substantiated. Do you have thoughts on this?

It's a fair statement to say the benefits of computational thinking in arts, humanities and social sciences have not been 'empirically substantiated', primarily because it's too early to tell—only now are researchers exploring the power of computation in these subjects. However, when I look at fields such as economics and social science

specifically, and even the humanities, computational methods are transforming these fields. New programs around the country and around the world recognise the prevalence and importance of the digitisation of data. With the help of computational power, you can do a lot with digitised data that you couldn't do as a human being. And so the digitisation of data is bringing computational methods to all fields where you can search, manipulate, analyse and visualise the data. These methods will enable us to make new discoveries, to find patterns and to suggest new questions that people would never have thought to ask before.

For example at Columbia University we have a history professor who has been looking at massive amounts of declassified government documents and analysing them in new ways. By using computational methods and tools, he is able to make new discoveries about law, policy and history. As a human being, you could not make these discoveries on your own because you could not read all the data, you could not digest all the data, you could not remember everything you've looked at, and so, you could not find specific patterns across all those documents. And that's just an easy example. At Columbia and elsewhere, people in all fields are recognising the value of data to making new discoveries and making predictions. I was just talking to a colleague in Economics this morning and he was rattling off many examples of his work with data, all of which have important implications for economic policy, decision-making and prediction. We are at the tip of an iceberg considering all the data that is being digitised and people in all fields now having access to online datasets that didn't exist before.

More specific to the creative arts is the ability to use technology to digitise artefacts, media and structures. Here I'm talking about emerging fields such as digital art, digital humanities and digital archaeology. For example, we can digitise historic relics—what you might see in museums—and then provide anyone around the world access to explore these artefacts. You don't have to travel to a remote place to enjoy the beauty and culture of other regions around the world. It's a different kind of globalisation if

you like—it's one way to bring different cultures together through shared access of digital data.

Finally, I would like to add that computational thinking is itself a very creative process. As with any problem-solving, it relies on human ingenuity, flashes of insight and taste in design.

You touched on this earlier when we were talking about the K-12 computational thinking concepts. One of the challenges is how can it be measured or assessed, particularly in non-computing disciplines. What do you see as the way forward on this?

Any educator would ask this standard question: How do we measure or assess whether one has learned a concept or not? Early on, I encouraged computer scientists to work with education, learning and cognitive scientists to figure out answers to this question. When I teach college students, I know how I might test a particular concept such as whether someone can write and analyse an algorithm, or whether someone can look at code and argue whether it does the right thing. There are various ways to test and measure the understanding of computational concepts. The bigger picture is still up in the air: How do we measure and assess at the K-12 level?

That's why, as much as I am very excited to see the progress we have made in the K-12 space, we need to temper our enthusiasm because we are still exploring and experimenting. We really do not know when is the right age to teach what concept or what is the degree of reasoning capability a child needs to learn a given concept. I don't have good answers to these questions, but as long as the education and computer scientists are working together, we will make progress.

What are your thoughts on the growing use of and interest in AI and data science?

The progress we are witnessing today in AI is due to the convergence of 'big data' and 'big compute'. What do I mean by that? The AI-based algorithms that people use routinely today in

industry are successful because they can be fed with lots and lots of data, so that's the 'big data' concept. The second part is that these AI-based algorithms are compute hogs, meaning that they take lots and lots of processing capability that is best run in the cloud. The cloud provides huge numbers of servers, including huge numbers of central processing units, graphical processing units and other kinds of specialised processors. AI is successful today because algorithms can be fed with lots of data and can be run on these huge computing clusters.

Advances in AI today come from having data. Thus, in terms of the future, data science is even more fundamental to society's digital transformation than just AI. The amount of data we produce continues to grow exponentially. Since we are going to be generating more and more data, we will be analysing more and more data. More data will certainly empower AI to be more sophisticated and more capable. This trend is not going to end, and so we need to adapt to it.

We also need to think about the consequences and implications of more and more of our world being driven by AI-based software. This world is very different from the world of today or yesterday where we had software all around but it was designed to be as predictable as possible. For AI-based algorithms the answers are probabilistic. A prediction or classification by an algorithm is made with some associated probability, leaving room for uncertainty. Thus, given the output of these AI-based algorithms, any decision you make or action you take is based on likelihoods. Probabilistic reasoning is very different from purely logical reasoning, the basis of traditional computing: 0s and 1s, on or off, right or wrong, yes or no.

We need to embrace uncertainty. There is uncertainty everywhere. There is uncertainty in datasets: they can have missing, imprecise or inaccurate values; they can have noise. Mother nature is unpredictable, the physical world is unpredictable and humans are unpredictable. Yet our software systems are going to have to operate in these unpredictable environments and interact with each other and with us humans. The way that we embrace uncertainty in computer science is to use probabilistic reasoning.

Probabilistic and statistical reasoning underlies all modern machine-learning techniques and tools. Since these technologies are not going away, we need to consider what needs to be taught in school. We should emphasise not just discrete mathematics but also probability and statistics. Expecting knowledge in these subjects has implications in terms of school education.

In a 2006 article you wrote, 'Computational thinking is a way humans solve problems; it is not trying to get humans to think like computers'.[2] Eleven years later, with the rapid development of AI, it seems we are getting closer to making computers think like humans. Is it likely that computers will soon do computational thinking better than humans; for example, self-coding AI?

It's a great question and the whole idea of self-coding AI is a new, active area of research. It helps to distinguish between the AI we can do today and the holy grail of AI. In a 1965 conference at Dartmouth, very prominent computer scientists got together and founded the whole area of AI. Their vision was to build a machine that could mimic human intelligence. This vision is the holy grail. Very early on, however, they realised that the general AI goal was way too big a problem to tackle. Instead, the research community divided the intelligence of humans into subcategories: speech, vision, language, planning, decision-making, mobility (e.g., walking or manipulation; for instance, with your fingers) etc. Each of those subcategories then became its own big field within computer science.

It was only in the early 2000s that all of these separate strands of AI started coming together because many of them were using common techniques, specifically machine learning. If you use the same technique for vision as you do for speech, as you do for natural language processing, as you do for machine translation, as you do for robotics, then all of a sudden there is something quite tantalising in thinking we can go after the 'general AI problem'.

To be honest, solving general AI is really far off, if you look at what we can do with today's AI. We can train a machine to process images to recognise objects; it's a human-level task, but it

is just a single task that humans happen to be good at. We can also use loads of data and compute power to train a model that can recognise English speech; it's a human-level task, but again it is just a single task that a human can do. We cannot build a machine today that can do all of the things that a human can do all at once. We can build little machines, each of which can do a single task that humans are good at. So we are far from solving the general AI problem.

Even so, some machines are as good as humans at performing some tasks, such as object recognition or speech recognition. Some, such as the Go computer program that beats human Go players, are even better. But most of our current AI machines or agents are still worse than humans. So we don't have general AI yet, and even most human-level tasks that we are nailing today with machines are still not as well done as by humans. In short, we have a long way to go before we have anything resembling a machine that has the general intelligence of humans.

To focus specifically on self-coding AI, there is definitely interesting research going on at Microsoft Research and other places, where people are using AI techniques such as machine learning, and deep learning specifically, to synthesise code and programs. Once we can succeed at this task, an interesting question is whether these AI agents will replace programmers as we know them today. I think replacing programmers is a ways off because current research is barely scratching the surface, though the results show feasibility. Even so, the task of programming is only one small part of software engineering, what is practised in industry. Much individual human thought, human-to-human communication and teamwork are needed to build large software systems. I don't see software engineering jobs being replaced anytime soon.

You asked me about whether computers could do computational thinking better than humans. Given that computational thinking is really about tapping into the creativity of humans to understand problems and express solutions so that a computer can carry them out, I don't think we are there yet. Perhaps what you are really asking is: Can these AI agents think creatively? It's hard

to do technically. More difficult is to define what creativity is, let alone measure it.

Accenture released findings from a global study earlier this year outlining the potential jobs that could be created by AI.[3] It highlighted trainers, explainers and sustainers of AI. Do you think education systems are focused enough on developing the computational thinking that students will need for the jobs of the future which will require them to work alongside machines?

This question needs to be unpacked because there are a lot of questions within it. First of all, do I think that education systems are focused enough on developing computational thinking? As we discussed, more and more countries are looking at their K-12 education and trying to promote the teaching of computer science. This transformation will happen over time because of demand and because these skills are teachable to K-12 students.

About jobs of the future, it is true that advances in AI are going to automate some jobs that today are done by humans—no question. Technology has always caused the loss of some jobs, but it has also created new kinds of jobs. We should be thinking about what those new jobs might be and what are the skills we need to teach children today or retrain current workers to learn so that they can do these new jobs. A relevant economic and societal concern is that as automation takes over a job previously done by a human, the person who no longer has a job may not have the new skills for the new jobs or have the desire to learn the new skills needed. It's important for society to prepare students properly for the new jobs that will emerge, and also to think carefully about how to encourage and help people who have lost their jobs to automation to learn new skills.

The third part of the question has to do with humans working alongside machines. Machines are never going to replace humans completely, but more and more humans are going to have to work alongside smarter and more capable machines. For them to work effectively together, humans and machines will need to

communicate at a higher level of discourse than they do today. Right now, machines produce answers, perhaps probabilistic, that a human needs to interpret and then make a decision or take some action. If the human doesn't understand how to properly interpret the answer the machine produces, then something can go wrong. Similarly, the way in which humans communicate with machines requires either simple spoken commands or low-level instructions written in a machine-interpretable language. Raising the level of communication between humans and machines is a research problem.

Another emerging phenomenon is the combination of humans and machines that can solve problems that neither can solve alone. This combination requires humans and machines to understand what each other can and cannot do and to understand what each other knows and does not know. A nice example of this combination is a kind of robot called CoBot, which a colleague of mine at Carnegie Mellon University built. It's called a CoBot because the robot knows what it doesn't know, and when it needs help, it turns to the human and asks for help. Specifically, this CoBot can roam the hallways, deliver water and mail, and escort visitors to their host. But when it gets to an elevator door, since it doesn't have hands, it needs help from a human to press the elevator button. So it stops and turns its cute robot head to the human alongside it and says, 'Would you please press the elevator button?'. The elevator opens and the CoBot walks into it. And then someone has to push the floor button. This kind of interaction that the CoBot has with a human shows that the robot knows what it doesn't know, and when it needs help it asks the human.

NOTES

1. Definition with input from Al Aho at Columbia University, Jan Cuny at the National Science Foundation and Larry Snyder at the University of Washington. For further information, see: Wing, Jeannette M (2014). Computational Thinking Benefits Society. *Social Issues in Computing*, 40th Anniversary Blog, 10 January. http://socialissues.cs.toronto.edu/index.html%3Fp=279.html

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CHAPTER 9

Nurturing '21st Century Skills' in Early Childhood Education and Care

IRAM SIRAJ

In writing about what we need to do in early childhood education and care to help our children cope with a fully fledged age of artificial intelligence (AI), I will avoid rehearsing the utopian and dystopian perspectives addressed elsewhere (if you are unfamiliar with these, please read Tucker in this volume). Instead, I am more interested in outlining the knowledge, skills, attitudes, values and competencies that the very young (and those who work with them) will require to cope in the different worlds of work and leisure which will come in the wake of AI's continued expansion and development.

It may be a truism that the future will be different, but human expectations have rarely been so high about the degree of imminent change. This century's rapid development of AI and digital systems has convinced us that almost every aspect of our children's and grandchildren's lives will be different to ours. It seems likely that future generations' patterns of un/employment and working will be drastically different,[1] and that, therefore, political systems will need to reconsider how their populations can best

be educated and live fulfilling lives. As governments often look to education systems to produce economic prosperity, enhance social cohesion and improve people's life chances, educationalists should offer creative solutions to people's future needs and their possible future problems.[2]

Current trends show that a skills gap is already widening in STEM subjects and in both non-cognitive and cognitive areas. The growths in social media prevalence and life expectancy also appear to be influencing wider meta-challenges around social wellbeing—largely due, it seems, to increased loneliness in the young and older populations, which is described as being at epidemic levels.

The changing nature of work, with both a concomitant growth in the need for interpersonal, analytical and creative skills and an associated decline in the need for routine, repetitive and manual skills, is well documented. Society's forward requirement for an adaptable workforce and a flexible adult population has never been greater.

It is often commonly suggested that we are heading for an age of skilled and connected 'knowledge workers' who can work, and who will work, from anywhere. It is certainly true that digital technology has already started to change the ways in which we work, play, communicate, do business and socialise. As these emerging technologies evolve and are then quickly replaced by as-yet-unimaginable new ones, human society will need to become increasingly nimble and adaptable—with lifelong learning as its modus operandi.

WHY FOCUS ON THE LITTLE KIDS?

When mass schooling began in the late 19th century, societies were relatively information-poor and governments decided what content should be taught. In this digital age, with information readily available and multiplying geometrically, the need for children to learn and memorise facts is diminishing, and is being replaced by the need to learn how to sieve and assess information critically for any kernel of 'truth'.

Today's preschoolers will enter the workforce around 2035 and, although we cannot contemplate exactly what their world will

then be, we do know that children and adults will continue to need the basics of the 'three Rs' (reading, writing and arithmetic), and that they will also need a greater ability to learn how to learn, and to possess problem-solving and critical-thinking skills, and to be resilient in the face of fast-moving change.

The period from birth to five years is a remarkably rapid stage of development in all children's lives. During this period, children experience a phenomenal increase in their cognitive, linguistic, social, emotional and physical development, and their brains are extremely sensitive to environmental influences. After five, the amount of effort it takes to learn new skills increases greatly. This means, therefore, that what happens in the early years has a profound effect on children's development, school success and later life chances. The physical, social–emotional, cognitive and linguistic capacities which emerge in these early years are the vital foundations on which the development of 21st century skills will rest.

All societies should already be considering what their children should learn in their foundational years to help them develop the knowledge, skills, attitudes and values for a fulfilling life in the AI age. A growing body of international research on the foundational years has revealed much about the influences on children's early learning and development. These include high-quality studies like the E4Kids Study in Australia, and the Effective Provision of Pre-school, Primary and Secondary Education (EPPSE), the Study of Early Education and Development (SEED) and the Millennium Cohort Study (MCS) in England.

It is incontrovertible that young children are reared in homes with vastly different material, social and cultural capital, yet those from the poorest homes receive a second chance to boost their potential by attending high-quality early childhood education and care (ECEC). And if they attend for a longer period, they benefit even more.[3] Their experiences in ECEC, however, must be the right 'high quality' ones for this 'compensation' to materialise.

Much has been written about young people needing strong '21st century skills' to thrive in the future world of work. These are generally considered to include a mix of cognitive and

non-cognitive skills which are not new to early education. Even so, I suggest that we need adults in ECEC who are more skilled than ever before to deliver these skills to our under-fives.

This depends, of course, on the kind of curriculum we deem most appropriate for our young. We also need to understand that parents and the home environment have an enduring impact on children's development, and to consider this in any approach to early learning. Indeed, the best early educators already work with both young children and their families.

WHAT SHOULD WE BE TEACHING IN ECEC?

Most discussions about '21st century skills' emphasise the need for schools to focus more on so-called 'soft' skills and character traits (such as creative thinking and curiosity) in addition to cognitive skills (such as problem-solving, critical analysis, the attainment of core subject knowledge, and strong early literacy and numeracy). Early years learning already tends to focus more broadly on 'whole of child' development than school education, and early childhood education already includes a strong focus on the 'soft' skills that form part of the skill set likely to be critical for future success.

One such key skill, which is being valued above others and seen as essential for learners, is self-regulation. Blair describes self-regulation as a general goal for child development and includes the following skills and abilities that children should acquire: 'be exuberant, run and play but also sustain attention and stay focused; be emotionally expressive, but also regulate emotion; take initiative but also comply; be conscientious in social interaction'.[4]

Blair goes on to point out how these skills are essential for lifelong learning and coping with more-formal schooling. Clearly, these skills also require children to have developed a good grasp of spoken language because they need to understand 'turn taking' and to have the ability to communicate their wants and needs. Children need to be able to be enthusiastic and curious in approaching new activities, to pay attention and follow directions, to not be disruptive, and to have the ability to be sensitive to other people's feelings.

Sylva et al., as part of the CARE project on quality and curriculum frameworks in Europe, identified three domains of learning

for 21st century ECEC.[5] First, there is a need for young children to develop both a positive self-concept and the ability to engage in social relations. This requires educators to address issues around children's abilities to communicate, collaborate and develop a sense of confidence and emotional self-regulation.

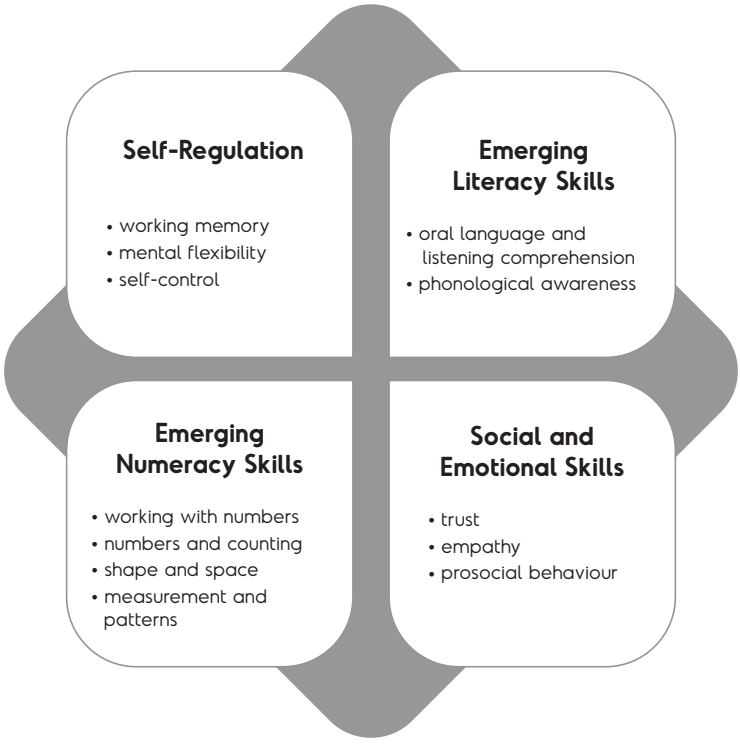
Second, there is a need for learning processes which include cognitive and behavioural self-regulation and executive skills. This includes the ability to persevere and concentrate, even when a task is challenging. Children should learn through their everyday activities and experiences of play to develop critical thinking and reasoning, organisation and planning, problem-solving, decision-making, curiosity, creativity, self-management, adaptability and an enthusiasm for learning. This requires a more intentional pedagogy on the part of teachers, where they ask children more open-ended questions and to explain how they know something.

Third, there is a need for young children to experience the acquisition of knowledge and content—alongside specific skills. This includes emergent academic skills such as early literacy, numeracy, scientific and technological knowledge, and rich social and physical activity. This requires their educators to present children with content which is rich and meaningful and helps children to develop both knowledge of the world and critical and higher-order thinking skills. Again, educators need the skills to 'coach' children to be peer tutors and to explain things to another child, and thereby increase their reflectiveness and their ability to match language to experience in a meaningful way.

Recently, the Organisation for Economic Co-operation and Development (OECD) designed a study to investigate children's early learning and wellbeing. The International Early Learning and Child Wellbeing Study (IELS) will focus on the development of five-year-olds in different countries. It is a much broader assessment of what children 'can do' than has traditionally been measured in the early years. Figure 9.1 shows the four domains.

This OECD study will take a more holistic approach, exploring a range of outcomes, including children's social and emotional wellbeing and self-regulation, and their emerging language and numeracy skills. It will also, unusually, include a child's

Figure 9.1 The Four Early Learning Domains to Be Studied in the OECD IELS



Source: OECD (2017). *Early Learning Matters*. http://www.oecd.org/edu/school/Early-Learning-Matters-Project-Brochure.pdf

understanding and development of trust and empathy, which will be necessary traits for their future social development. As Tucker says in this volume, the most essential educational component for the coming education system will be to better understand what it means to be human.[6]

Tucker goes on to emphasise the importance of children not only understanding the basics and STEM subjects, but also the arts, literature, creativity, social sciences, culture and humanity. He suggests that children should learn about another culture which is different from their own. If we really are about to enter an age

where AI has global repercussions, we surely need to develop these understandings from the earliest age. I would contend that children should be learning in ECEC about similarities and differences in culture, in religion and generally in people, and that they should be shown how to understand and be open to difference and other ways of living, rather than to be fearful, closed or intolerant.

We do not yet know how the OECD study data will be used by countries involved in the IELS, but hopefully there will not be a simplistic move to league tables with pressure on ECEC for more 'schoolification'.

There is a growing emphasis on integrated learning in ECEC that creates a connection between the academic and the social. The development of children's competencies in creativity, collaboration, self-regulation and problem-solving can be undertaken through projects which harbour real-world knowledge, and through problems which require young children (especially those aged three to five) to communicate and create knowing together. Here, the important task of the educator is to emphasise, and give attention to, the learning process rather than the learning outcomes.

Connected to this is the importance of educators emphasising interactions that support sustained shared thinking (SST). SST occurs when two or more individuals 'work together' in an intellectual way to solve a problem, clarify a concept, evaluate an activity, extend a narrative etc. Both parties must contribute to the thinking, and it must develop and extend the understanding.[7] It is still rare to see SST in ECEC settings, but research shows that children are more successful learners, and better motivated to learn, where it is practised.[8]

HOW CAN ECEC SUPPORT PARENTS TO STRENGTHEN THE HOME LEARNING ENVIRONMENT?

It really matters what parents do with their children in the home. Given that children's development is so rapid in the first five years, any ECEC system which ignores this reality will not be able to optimise children's potential.

Future learners will need an excellent start in early learning if they are to cope with mid to late 21st century challenges.

The EPPSE study was one of the first to show that (i) 'what parents did' with children at home was more important than 'who they were'; (ii) supporting stimulating learning environments at home leads to better learning in a number of domains in preschool; and (iii), these benefits in learning continued to show well into primary and secondary education.

Just as it is vital that ECEC curricula emphasise the process and the outcomes of both soft and hard skills to create the most competent learners and citizens, so too is the family's role essential in nurturing and enriching young children's development.[9] The critical home activities include reading, talking, playing with letters and numbers, and singing and drawing with young children.

Structured parent–child interactions centred around books or joint play are another strong component of the effective early home-learning environment. Language development and talk are vital in all child development, but these are harder to deliver in group provision. Although there should be a strong focus on them in ECEC, families are in a stronger position to ensure that children have a rich language experience. After all, parents provide the language which draws on the embedded, contingent experiences that they have with their children on a daily basis.

Most ECEC systems make less provision and funding for children under three because their care and education is very expensive, yet it is precisely these years when the family's influence is the greatest. Future ECEC systems should provide stronger support for local families with younger children, and there is no reason why some of this support cannot be offered through digital technologies, streamed directly into the home, which help parents learn about the power of early child rearing, and sensitive, responsive care and appropriate interactions. In such a system, ECEC staff can offer more support to families living in challenging circumstances.

Evidence suggests that intergenerational support, delivered through ECEC centre-based provision, is more powerful in terms of impact. If we believe that the early years are important, we need to realise the potential of all those who share in the care of our youngest children. Indeed, developing and nurturing

intergenerational support allows ECEC staff to stimulate history learning-and-understanding skills through a creative use of simple oral histories. This has implications for widening the role of ECEC staff, but a clearer understanding of the way that others have handled and adapted to change in the recent past will help prepare children to deal with the challenges and changes that they will inevitably face.

DEVELOPING A WORKFORCE THAT CAN MEET THE CHALLENGES OF ECEC FOR THE 21st CENTURY

It can be argued that, currently, no single country has established an outstanding ECEC system across its whole nation. Some propose Scandinavian countries as beacons of hope: a few of these do have well-developed centres, with highly qualified staff, state funding which supports all families, and more provision for the under-threes. This is reflected nationally in their funding models and retained through universal taxation.

The best national ECEC systems are stronger on the project work which Tucker describes in his essays as the way forward for schools, and which helps children to deal with an integrated curriculum using real-world problems to make connections and to work both collaboratively and creatively.[10] Even within these 'good' systems, however, there is great variability[11] and limitations due to a focus on the processes of learning and a lack of emphasis on the educational component of ECEC.

In a recent workforce review, Siraj and Kingston demonstrated the fragmentation of ECEC systems, with variable funding and training streams which reproduce inconsistency in the quality of staff training and practice.[12] There is now good and growing evidence that high-quality training impacts children's learning outcomes (social and cognitive).

The NSW Department of Education recently funded the Fostering Effective Early Learning (FEEL) study and an associated literature review,[13] which shows that providing staff with high-quality training in areas such as self-regulation, language development, high-quality interactions and both relational and intentional pedagogy (focusing on both the 'process' of meaningful

learning and concept development) is a key factor in promoting children's developmental outcomes.

More importantly, the FEEL study shows that high-quality training increases staff confidence both to improve children's autonomy and agency and to focus on their own planning and reflection on the needs of individual children. FEEL's professional development was coupled with pedagogical support to scaffold educators' learning in key areas of knowledge, skills, competencies in child development and intentional and relational pedagogy. In an intervention of just over six months, there were improvements in four outcomes for children in the intervention group.

Professional learning and ECEC teaching need to incorporate SST within meaningful contexts to support children's communication, language, thinking and learning. This requires highly skilled staff who are knowledgeable in children's learning and development, early assessment, and monitoring and supporting children's physical, socioemotional, linguistic and cognitive development. Staff need to ensure that children are safe, stimulated and ready to learn, think deeply and make connections with the knowledge they have. In order for ECEC educators to possess this knowledge and skills, they themselves need teaching by academics who are familiar with the concepts, can model them well, and are able to apply theoretical bases to real-life practice.

This fits with research findings that the key to promoting successful learners in ECEC is for educators to be skilled in play-based, child-directed activities which are planned in advance using reflective tools, and that educators embed academic content with intentionality.

In the teaching process, ECEC educators should scaffold or structure children's learning intentionally through providing feedback and encouragement, and through allowing children to exercise their autonomy and agency within the context of regulation with peers and adults. Such a pedagogy depends on strong emotional and secure relationships with children, and sets the stage for children's self-regulation and the later emergence of executive function and the higher-order thinking which will be a critical factor in any mid to late 21st century skill set. Primary and

secondary schools will benefit when children leave ECEC with these skills, and they will have to develop them in the children when they do not exist—but this will be harder.

The OECD states that staff qualifications, initial education and continued professional development can contribute to the enhancement of

> pedagogical quality, which is, ultimately, highly associated with better child outcomes. It is not the qualification per se that has the impact on child outcomes but the ability of better qualified staff members to create a high quality pedagogic environment. Key elements of high quality are the ways in which staff involve children, stimulate interaction within and between children, and use diverse scaffolding strategies.[14]

Despite this, in terms of the wider education system, the early years generally contain the least qualified and worst-paid staff, and few opportunities to foster deep, pedagogical leadership skills. When ECEC provision is genuinely high-quality, there can be lasting population change for good, but the government investment in knowledge, capital and labour must be commensurate.

RE-ENVISIONING ECEC

If we are heading for an age that requires skilled, connected, sociable and adaptable 'knowledge workers' who can work collaboratively, independently and creatively, the solution does not lie in our youngest children spending long periods in screen time. Too much screen time at an early age deflects children from developing the essential human skills they need to function in complex social and economic work. Plus, we already know that increased use of digital devices at an early age is associated with poorer outcomes.

Good ECEC teachers, and likewise parents, resist the temptation to use screen time for child entertainment and control; rather, they show children how technology can serve our needs as tools that we turn to, at times, within our play and work. Rather than considering digital devices as a panacea, we need a more sophisticated pedagogy and curriculum (and, indeed, educators themselves)

which, alongside the three Rs, emphasises language, communication, creativity, collaboration and the 'softer' skills mentioned throughout this essay.

Perhaps it is time to construct a new curriculum and to create a re-envisioned ECEC system which includes a workforce of high quality, which is fit for purpose, well rewarded and well educated. Such a re-envisioned system may truly provide the foundational learning our children and grandchildren deserve—and which they, and all their fellow citizens, will need to sustain them and to face the challenges thrown at them by the brave new world we have entered.

NOTES

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