The future of product design education Industry 4.0

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Chapter 10
The Future of Product Design Education Industry 4.0

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ABSTRACT

When a society is undergoing transformational change, it is a challenge for all involved to step outside their immediate context sufficiently to evaluate its implications. In the current digital revolution driving Industry 4.0, the pace of change is rapid, and its scale and complexity can inhibit a proactive, rather than reactive, response. Yet if it were possible to return to the first industrial revolution, armed with twenty-first century knowledge and historical perspective, planning for a healthy society and the future of work could have been very different. This chapter aims to support educational leadership in the development of proactive strategies to respond to the challenges and opportunities of Industry 4.0 to inform the future of work, industry, and society. This is framed through the lens of product design, with its unique position at the nexus of engineering and the humanities, and directly tied to changes affecting manufacturing in the fourth industrial revolution.

INTRODUCTION

From disruptive technology to disruptive ideas, the early decades of the twenty-first century can be characterized as a period of non-conformity and new direction. Whilst globalization and amalgamation dominated economic strategy at the turn of the century, the predicted homogenization into a world without borders has been fractured by a backlash of nationalism and separatism, burgeoning entrepreneurship and new business practices based on a sharing economy. In this setting, the expectation could be that product design education would be working through a corresponding period of radical change, yet in many universities, with higher numbers and reduced funding, there are increasing pressures to conform to a modularized education system; design has become a linear process, and limited approaches to creativity

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are prescribed with diluted outcomes defined by business school drivers and design thinking approaches to interdisciplinary practice. This chapter questions the dominant influences in prevailing product design education, challenging existing thinking in the disciplines to call for educational reform in the face of outdated conventions and thinking. If the discipline is to remain relevant in this era of digital disruption and rapid technological advancements, then pedagogy must be subject to critical scrutiny in order to ensure that the pathways aligned with this approach are not restricted by existing practices and closed thinking. This chapter argues for academics to learn from the past and present in designing pedagogy and curriculum, informing the need for change to ensure authentic learning for product designers in the twenty-first century.

BACKGROUND

Product design emerged as a profession during the eighteenth century in response to the drive towards mass production and the design challenges it created. According to design historian Adrian Forty, in his seminal book, *Objects of Desire* (1992), the earliest product designers in the UK employed by innovators, such as Josiah Wedgewood, were educated on European trends in art and architecture, as well as the reduction of a design into repeatable components. Production uniformity and aesthetic conformity became megatrends of the time and were central to design development, allowing manufacturers to produce standardized products within an orderly system of centralized manufacturing. The impact on the organization of labor, and subsequently lifestyle and the urbanization of the population, was relatively gradual. During the late nineteenth and early twentieth century, however, as Ford established the moving assembly line, the pace of urbanization changed with large-scale factories drawing in workers from large distances (Sparke, 2013). For designers, their role became increasingly constrained by mass-manufacturing processes and practices, with these being the driving technologies of the times. Design had to conform to assembly rules, and generally the lower the cost of components the higher the margins for business. For workers, the transition to working within a system where labor was divided to its most basic action became common place. The impact on the organization of society was immense.

The transition can be characterized as a shift from traditional hand production to massive industrial machinery and factory production. To a large extent it was stimulated by the invention of large-scale manufacturing processes fuelled by the discovery of new methodologies for exploiting the energy stored in huge iron and coal deposits. The subsequent access to apparently unlimited energy and human resources engendered by the rise of capitalism and individual and corporate entrepreneurship and innovation, marked a major transition in human affairs. The Industrial Revolution was the socioeconomic equivalent of the Big Bang. (West, 2017, p.211)

Following the Second World War, building the economy was seen as paramount, with marketing and mass production scaled up. This drive meant that designers during the twentieth century were frequently locked into the contradictory practice of trying to design the best possible outcomes yet encourage obsolescence for repeat sales. Dissenters, such as Victor Papanek, argued for a sense of moral responsibility in design. He was shunned during his early career following the publication of his seminal work, *Design for the Real World* in 1971 (revised edition 2005), but as the social and environmental impacts of mass production began to be understood towards the end of the century, attitudes to his work within the design community began to alter. By the nineteen-nineties, Papanek's book was required reading in design schools as environmentally-conscious, socially aware design gained momentum. The straightforward design – or redesign – of commercial objects for mainstream retailers was replaced in design schools by the responsible design of products for specific challenges facing society, with the lifecycle analysis of the product integral to the work. A century after the role was introduced as a taught profession (attributed to the Deutscher Werkbund established in 1907, precursor to the Bauhaus (Droste, 2015)), the environmental and social impact of the work of the profession and the manufacturing and marketing parameters that it had been established under, were, to a large extent, discredited (Hawken, 2010). Sustainable design became central to the teaching of product design in universities with lifecycle assessment, extended producer responsibility and designing for the circular economy core to industrial design education for the twenty-first century (Walker, 2006).

Whilst the terms 'product design' and 'industrial design' are often used interchangeably, the latter is arguably more systems oriented than the first, but both are closely linked to the emergence of mass production and consumer culture in the early 20th century (Fiell & Fiell, 2006; Walker, 2006). Over the last forty years, the perception of the role of the product designer in higher education has changed significantly (Loy, 2012) as the social and environmental impacts of design for production have become better understood. As a discipline synonymous with large-scale manufacturing and distribution, product design has shaped the physical world through the creation of objects constrained by economic manufacturing drivers, such as standardization and repeatability. Based on this, Walker (2006) argues that the very terms product design and industrial design therefore carry with them an associated baggage that may no longer be suitable in the twenty-first century as new technologies disrupt traditional modes of design and production. This is part of broader digital transformation impacting manufacturing today, termed Industry 4.0. Much like the earlier Industrial Revolution's embrace of the latest technologies of the times, Industry 4.0 encompasses today's latest technologies including artificial intelligence (AI), machine learning, the Internet of Things (IoT), and ubiquitous computing, and will radically alter the world of work, education and consumer relationships with products.

Designers no longer focus on purely human-centered design and the functioning of the product and its stylistic appeal, but rather on the product service system it operates within. The agency of the product is recognized as impacting behavior and sustainability, and is as core to the design as its economic viability. As Tatum discussed in his *Design Issues* (2004) article on design responsibility, every design decision, however small, has consequences because of the cumulative effects of incremental change. From an environmental perspective, the next twenty to fifty years will be critical, and design education needs to anticipate the challenges coming. Founder and Executive Chairman of the World Economic Forum, Schwab (2017) explains that the fourth industrial revolution:

began at the turn of this century and builds on the digital revolution. It is characterized by a much more ubiquitous and mobile internet, by smaller and more powerful sensors that have become cheaper, and by artificial intelligence and machine learning… By enabling "smart factories," the fourth industrial revolution creates a world in which virtual and physical systems of manufacturing globally cooperate with each other in a flexible way. This enables the absolute customization of products and the creation of new operating models. (2017, p. 7)

Product design must necessarily evolve from its roots in the first industrial revolution to maintain relevancy in this new era of digital technology. With boundaries between the physical and digital worlds blurring through digital fabrication technologies, such as additive manufacturing, the demand for product designers to standardize manufacturing and develop one-size-fits-all products is being removed. Additive manufacturing (AM), also known as 3D printing (3DP), is comparatively new; it refers to a range of technologies fed directly by three-dimensional computer-aided design (CAD) files. Described by Gibson, Rosen and Stucker (2015, p. 2), the object is "fabricated directly without the need for process planning... the key to how additive manufacturing works is that parts are made by adding material in layers; each layer is a thin cross-section of the part derived from the original CAD data." This contrasts traditional plastics manufacturing technologies, such as injection molding, which requires significant investment in machining molds before a single product can be produced, with manufacturers needing to sell high volumes of parts from each mold in order to recoup their initial investment and make a profit. The significance of additive manufacturing is that the creation of molds and tooling, and therefore the need to design and sell standardized products, is removed. This has led to a realization of mass-customization, also referred to as mass-personalization, (Hu, 2013; Tseng, Jiao, & Wang, 2010) whereby the 3D CAD file describing a product is altered to suit the unique functional or aesthetic needs of an individual. Objects of similar dimension yet different detail cost approximately the same to 3D print. This is resulting in the 3D printing of high-value customized products such as hearing aids, medical implants and orthotics.

In the twenty-first century, a confluence of innovation based on digital technologies is creating a paradigm shift in industrial practice. Whilst AM is just one example of a technology contributing to the fourth industrial revolution, it is the catalyst for a shift in thinking from mass production to print-on-demand and representative of the changes facing designers. In Industry 4.0, factory automation is increased, along with the monitoring of different facets of production. This includes machines, the progress of the part and the quality of the part at each stage of manufacture. The supply of materials and additional components could be integrated into an automated extension of the 'just in time' (JIT) approach. However, when the practice extends beyond the factory and the collection of data, the analysis of data, and automated responses to changes in the system, the approach moves beyond incremental manufacturing efficiencies. Where distribution and product lifecycle are monitored as part of product service systems, this data is fed back to the organization, providing insights on product performance, adaptation and interaction as part of a connected workflow. This approach is enabled by the drop in cost of monitoring systems, increased sophistication of algorithms and communication within systems (termed the Internet of Things), due to developments in 'Cloud' storage (Seldon & Abidoye, 2018, p. 137) and wireless connectivity.

On a practical level, this shift requires serious up-skilling of academics and upgrading of facilities in higher education to prepare students for their new role within a cyberphysical manufacturing system. However, more fundamentally, academia needs to lead an understanding of the implications of transformational change in this sector to develop strategies and policy for the future of work and industry. The changes currently occurring have the potential to impact societies, the environment and economies. Product design programs and research in higher education are central to these changes and therefore academics need to be providing leadership in addressing the long-term implications of decisions made now, informed by history and a reasoned mapping of the changes about to come.

EDUCATIONAL FRAMEWORK

Learning From History

With the benefit of experience gained by looking back at the long-term consequences of earlier industrial revolutions, both positive and negative, the recognition of a coming paradigm shift should theoretically allow societies to be better prepared for the widespread change that accompanies an industrial revolution. The impact of technological change on the organization of work and the subsequent impact on societies should be central to discussion on the implementation of technological interventions to production systems, such as automation and machine learning, characteristic of Industry 4.0. However, in his book *Are Robots Taking Our Jobs* (2017), Cameron suggests that when considering the changes brought about by digital transformation, people - and therefore organizations - have an inability to comprehend the scale, scope and speed of change. This is because its impact and complexity will be on a different scale because of global connectivity, and it is therefore challenging to view in its entirety. It is also difficult to view different aspects through a narrow lens to try to build a larger perspective, because of the lack of conventional organizational borders and hierarchy in thinking it engenders, and its challenge to existing heuristics. New ways of thinking about the world will be required to provide education with accessible strategies to assess the implications of the paradigm shift, and to attempt to mitigate problems it could create, as well as frame and address problems it could solve.

Higher education has a responsibility to prepare future citizens for their role in society and as the future workforce. With Industry 4.0, this will involve training to ensure the workforce are equipped to cope with the new technology, but more fundamentally, it should involve developing values and aspirations for society informed by the opportunities and challenges digital industrialization will bring. It will also involve attempting to anticipate the changes to people's lives on a daily basis, such as the need to change infrastructure and ways of working. In general, as the concept of Industry 4.0 emerged from the German car industry, it is seen as increased automation and maximized throughput. However, the term more broadly refers to an increased ubiquity of computing capability across manufacturing and product service systems. Increased monitoring systems, generating data, analyzed by algorithms as the basis for operations within the factory changes the way manufacturing operates. However, when monitoring is expanded out to the distribution of the product and its interactions during its lifetime, this informs the factory on future demand and working as part of a system to feedback information on its operation and performance, and changes the way people and products interact.

In disciplines based on the design of manufactured products and product service systems, such as product design, a simple analogy would be moving from 2D paper-based drawings to 3D computer models, as has happened over the last thirty years. For designers, and design educators, it has required a different way of understanding and manipulating form. Expertise in traditional 2D working drawings was no guarantee of expertise in computer 3D modeling – it could even be a hindrance as it predetermines the expectations of the designer. In a similar way, Industry 4.0 heralds a shift from 3D to 4D product modeling, where the entire life of a product is considered during design, with the product possibly having the capacity to update or adapt through time as needs and circumstances change (Novak & Loy, 2017). This is because the digital technologies that inform developments in Industry 4.0 allow for connected products to also be responsive, and therefore develop into complex systems. For industry and academia to respond, thinking needs to be disruptive and informed by new knowledge. Furthermore, Schwab describes that:

While the profound uncertainty surrounding the development and adoption of emerging technologies means that we do not yet know how the transformations driven by this industrial revolution will unfold, their complexity and interconnectedness across sectors imply that all stakeholders of global society - governments, business, academia, and civil society - have a responsibility to work together to better understand the emerging trends. (2017, p. 2)

The challenge to educational strategists is to step outside traditional discipline boundaries, as suggested by Schwab, and build objective, new perspectives that respond to its transformative potential. Design education is by definition forward looking and requires strategies for facing the unknown, engaging in initial research, and creating new, objective views of the situation being faced that allow realistic problem-framing and solution development. Product design academics should therefore be ideally placed to envisage new perspectives for Industry 4.0 education to respond not only to the technological developments in isolation, but also their broader societal, environmental and economic implications.

In learning from the past, Walker (2006, p. 9) talks about previous design movements that have "challenged prevailing stereotypes and stimulated and influenced subsequent designers." Examples include the De Stijl group in The Netherlands, Bauhaus and the Italian Memphis designers. However, he also points out that:

the issues and agendas to which they were responding are not our issues and agendas. Today, we are facing new challenges associated with the globalization of industrial capitalism, the environment, national and transnational socio-economic disparities, and rapidly evolving scientific and technological developments. (Walker, 2006, p. 9)

Educators today need to learn from the achievements of the past, particularly in creating social change, but whilst the ideas need to be viewed in context, equally, they cannot be embraced by the current generation without critical review. This is demonstrated by Fuad-Luke (2009), where he considers movements in design history through the lens of sustainability in his book *Design Activism: Beautiful Strangeness for a Sustainable World*. This approach provides a critical examination of the past, in order to inform current thinking. The necessity of a revised approach to higher education responding directly to the potential future of work enabled by Industry 4.0 needs to be recognized. Product design provides the basis for this discussion because of its position at the nexus of engineering and the humanities, but the challenge to build a radically different educational response to the paradigm shift this industrial revolution effects extends across all disciplines – in whatever future form they emerge as traditional academic boundaries merge. There is a need for strategies to address educational change to keep pace with developments in digital technology but, more fundamentally, for higher education to prepare future citizens to recognize and respond to the issue of human development in a digital era.

Learning From the Present

The digital revolution at the turn of the century has transformed communication and interaction across the globe. Consequently, digital technology is changing learning and teaching for all disciplines. For industrial and product design, the digital revolution is exactly that – a revolution in ideas, aspirations, technological opportunity and direction. It challenges conventions in product design, manufacturing, development, the designer-producer-user relationship, and has the potential to allow for major restructuring in manufacturing systems around the world. This is particularly driven by the sustainability imperative, illustrated by the discovery of plastic waste in remote regions, including from arctic ice-core samples.

The highest density of plastic ever to have been documented was on an uninhabited coral atoll called Henderson Island in the South Pacific. Scientists studying the island estimated there were over 38 million pieces of plastic, with items from Germany, Canada and other distant places recorded. (McCallum, 2018, p.27)

Rethinking the future based on an in-depth, researched understanding of complex situations, and research into the opportunities and challenges provided by new technologies and their relationship to existing ones, whilst keeping the human experience, social and environmental responsibilities to the fore is surely fundamental to the product design discipline. But is this actually the case? Taking a critical view, is it the reality that in working to become an established academic field of research and education over the last thirty years in a competitive tertiary education environment, the discipline has been compromised? Is creativity education being reduced to predictable, manageable, linear exercises due to practical reasons or for accountability? Has a drive to employ academics with a decent H-index pushed industrial and product design educators out or under the auspices of an engineer? In a study into the relationship between research and teaching activities in tertiary institutions, Gunn (2018) found that the need to meet the requirements for producing research outputs and bring in research funding was distorting the priorities of the universities. Gunn (2018, p.153) argued that it was "an anomaly" in terms of a business practice, as the dominance of research focus directed resources away from serving the "customers" in the "core business." He explains how the environment in which UK universities have operated over the last twenty-five years has been transformed and there is a need to refocus on teaching to meet the requirements of a new educational era. The extent of the disruption of digital technologies to society and the future of work and industry has only begun to emerge. However, based on examples such as the online communication platforms supporting Uber and Airbnb, disruption is likely to have far reaching consequences. Academics will need to rethink the curriculum and pedagogy in response to the complex nature of the changes and prepare students for the unknown and the unexpected. However, has the very ability to respond positively and imaginatively to the unknown (a critical need for society in the face of disruptive change and surely characteristic of design), been rendered insignificant and even obsolete over that time because it is hard for institutions to quantify - or for those from other disciplines to properly replicate? Industrial and product design disciplines will need to step outside the confines of dominant, established academic practices and attitudes and take an objective look at the role of the designer in the twenty-first century, and an unfettered look at educational development that supports the discipline ideal irrespective of external influences and current ideas of what tertiary education and research should be. This is a time of change, and change is what design should be all about.

Over the last twenty years, elements of a design approach to problem framing and problem solving have been hived off by business, health, engineering and transdisciplinary programs. There have been two major problems with this: Firstly, those teaching within these programs are frequently not fully-fledged designers and therefore not adequately equipped to teach the subject effectively. Imagine if designers started to teach engineering without qualifications or professional experience; there would be considerable objections raised. Yet it appears that it is acceptable within tertiary education for this practice, which speaks to the current understanding of what design is, and the status of design programs in universities based on the current priorities of those tertiary institutions. Secondly, the elements of the design process that have been adopted by other programs are limited, resulting in a narrow interpretation of design and its application. In particular the systemization of a design process, as frequently presented in engineering programs and publications, is reminiscent of presenting a health care plan that does not consider the human element. The complications and subtleties of the situation are lost. Design is reduced to incremental and predictable actions.

Many design philosophers, such as Hugh-Aldersey Williams (2011), have drawn parallels between life after the digital revolution and life before the industrial revolution. The seminal work by economic philosopher Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations,* proposed that efficiency would be improved by the division of labor into the smallest possible increments within manufacturing (Forty, 1992). This approach has dominated mass production over the last hundred years, supported by a stock market driven economy where individual, short term gain has taken precedence over a holistic view of the human experience, contraction and convergence equity issues and long-term environmental impacts. Yet, as West (2017, p.211) points out, this approach is unsustainable: "As presently constituted, our continued success requires the supply of coal, gas, oil, fresh water, iron, copper, molybdenum, titanium, ruthenium, platinum, phosphorous, nitrogen, and much, much more to be available at an exponentially increasing rate." Digital disruptions include algorithms for stock market trading, the displacement of conventional banking with blockchain, and the highlighting of the inadequacies of existing regulatory systems to address changes in business practice, healthcare and manufacturing. These changes are happening quickly. As Seldon and Abidoye (2018, p.169) point out, academia's understanding of the changes in educational access with developments in AI can be outdated and its reaction slow: "Google is the greatest pedagogical success and it is a piece of AI."

In universities, even the introduction of programs can take a number of years, irrespective of public demand, because of the protective systems in place. When a program is added, it often must be justified by evidence of similar, successful programs elsewhere. It also needs to fit within the established program offerings and the organization of faculties, schools and departments. These processes make agile changes difficult. The reduction of risk in the introduction of programs also reduces the ability of a university to change direction quickly or to offer diversity in the programs that operate across traditional organizational boundaries. Given the rapid pace of technological change, this inability to adapt at a similar pace is cause for concern. To date, research universities have been secure in their position as educational providers. Yet complacency has a history of preventing sufficient preparation in the face of unanticipated or under estimated change. This is a dangerous attitude for all disciplines to have, including, as discussed, long-established and regulated disciplines such as engineering, but for design, there is really no excuse. Digital technologies have the potential to cause far more disruption than appears to be currently being predicted within educational institutions. "A growing national and institutional policy focus on teaching, and anxiety over the student experience, presents the chance for new narratives of investment in learning and teaching to develop beyond the hegemonic reach of research excellence and research-intensive universities" (Charles, 2018, p.28). Genuine, informed, engaged design education is not hampered by the weight of formulaic restrictions and discipline legacy. It has not only the freedom, but the imperative, to keep a watching brief for change and respond energetically to researching the possible futures on the horizon. However, in order to maintain integrity in this aim, industrial and product design disciplines need to disentangle themselves from the reflected status of disciplines that are currently the longest established, and most recognized as authoritarian in universities at this time. Design education needs to be founded on working with the unknown, and the constant development of new practices and approaches to explore, understand and address forever new problems and opportunities. Students and academics need to re-embrace that spirit of improvisation, and tertiary education needs to understand its value. Ways of working founded on this approach need to be revisited and formally developed, with an alignment perhaps closer to acting studies than current design education programs that are aligned to business or engineering.

Learning for the Future

According to Seldon and Abidoye (2018, p.169) “AI is impacting everyone, every day, but schools and universities are not consciously using it to exploit teaching and learning or adequately to prepare their learners for the AI-driven workforce they will subsequently encounter.” They continue:

Nothing but nothing is more important than education in ensuring that AI works in the interests of all humanity. We need to re-imagine our schools from the ground up to teach our young to be more fully human and not to be content any longer with giving them just ‘factory era’ skills.” (Seldon & Abidoye, 2018, p.312)

Seldon and Abidoye point out that in the UK, the Prime Minister’s Industrial Strategy, announced in November 2017, has AI as the leading component, and start-ups in London have grown from 16 in 2008 to 6000 in 2018. There have been fairly radical shifts for product design education over the last forty years – a relatively short time compared to other, more traditional disciplines, such as engineering and architecture. Yet the changes facing all of higher education in the rapidly emerging digital context are likely to disrupt product design education even more significantly because of their intrinsic connection to manufacturing and therefore AI. Seldon and Abidoye argue:

There is no more important issue facing education, or humanity at large, than the fast approaching revolution of Artificial Intelligence, or AI. This book is a call to educators everywhere, in primary, secondary, further and higher education (HE), and in all countries, to open our eyes to what is coming towards us. If we do so, then the future will be shaped by us in the interests of all. If not, others, the large tech companies, governments and even the bad guys will decide, and we will have only ourselves to blame. (2018, p.1)

The suggestion is that educational models will change and that governments must lead changes to modernize education. (Seldon & Abidoye, 2018) Artificial Intelligence in this context does not refer solely – or even predominantly – to humanoid robots, but to the automation of labor and its impact on the future of work and industry. For higher education, the challenges are both to prepare graduates for a digitally connected future, but also to radically evolve education, to create relevant pedagogy and curriculum in a digital age. The context and intent of a curriculum for the coming digital era needs to be informed by the dichotomy that is emerging in response to the rapid changes digital technologies are bringing. This dichotomy is exemplified by the contrasting opinions of Greenfield (2017) and Kelly (2016) on technology and society issues such as the ‘Quantified Self’ (Kelly, 2016, p.238, Greenfield, 2017, p.33). It is also illustrated for the general public in exhibitions such as ‘The Future Starts Here’ at the Victoria and Albert museum in London (Hyde & Pestana, 2018). Instead of a science-fiction, all white, technology-worshipping ideology, the exhibition presented a curiously dystopian view of developments in a vaguely post-apocalyptic setting. In a darkened room, with exhibition stands that look like the relics of a Bladerunner 2049 film set, cutting-edge research, such as the MIT 4D pneumatics prototypes, were shown alongside examples of digital-based interference in politics (both Trump and Brexit) and fake news. An example of 3D printing being used by designer Sarah Hendren and anthropologist Caitrin Lynch to support the individual needs of an amputee in the design of low-cost, bespoke assistive technology (Galloway, 2018) was positioned alongside a stand devoted to those who are working to extend life through strategies such as cryogenics and downloading the human brain.

For product design education, Industry 4.0-specific education is critical for future graduates. As products increasingly become connected to the digital world, and are created through entirely digital means, the questions for product designers have become bigger, shifting from how digital technologies such as sensors, the Internet of Things and additive manufacturing will affect products, to how it will affect product systems, industries, their organization and the future workforce. Education with regards to Industry 4.0 will need to comprise of two things: The first is the means to critically research and interrogate the opportunities and implications of technological change. The second is the ability to constantly update skills and understandings fluidly in a continuous state of change. Both are difficult to achieve in the face of the educational heritage that has built up over the last fifty years as education itself became more of a business, with changes to funding and the focus of universities generally leading to larger class sizes and more standardized learning. Traditionally a designer has gone through an education system where the content generally changes only incrementally and has worked in a career where the tools of designing, the processes and manufacturing technologies, change slowly, if at all. Whilst an occasional updating of skills might have been necessary – lifelong learning has not. However, design is currently in flux, linked closely with the burgeoning developments in digital technology: "Technology is humanity's accelerant. Because of technology everything we make is always in the process of becoming. Every kind of thing is becoming something else, while it churns from "might" to "is." All is flux. Nothing is finished. Nothing is done" (Kelly, 2016, p. 6). The education of designers must also now be in flux – subjects taught the same way as they were only a few years ago would arguably be setting students up for failure, as the knowledge they would graduate with would be outdated before they began their working career. Brown and Alder (2008) built on this idea describing that:

In the twentieth century, the dominant approach to education focused on helping students to build stocks of knowledge and cognitive skills that could be deployed later in appropriate situations. This approach to education worked well in a relatively stable, slowly changing world in which careers typically lasted a lifetime. But the twenty-first century is quite different. The world is evolving at an increasing pace. When jobs change, as they are likely to do, we can no longer expect to send someone back to school to be retrained. By the time that happens, the domain of inquiry is likely to have morphed yet again. (Brown & Adler, 2008, p. 30)

Therefore, lifelong learning must be embedded in design – it must be synonymous with the act of designing. Gore (2013) makes a similar point, arguing there is still too much emphasis in education on the memorization of facts: "Yet in a world where all facts are constantly at our fingertips, we can afford to spend more time teaching the skills necessary to not only learn facts but also learn the connections among them" (Gore, 2013, p. 67). The challenge is less about reshaping education for the students, as each new influx of students knows little about what has been taught in previous years, but rather how to transition design staff to embrace change, particularly if they have past industry experience in product design based in traditional mas-manufacturing technologies. Many academics (not just design) have been experts in their field, but as change brought on by digital technologies such as AI accelerates, many established practitioners and academics simply do not want to adapt and remain relevant. At what point does the need to prepare students for the future outweigh this experience of the past? Petko, Egger, Cantieni and Wespi (2015, p.49) observe that "research has shown that successful technology adoption does not so much rely on hardware and software but, more importantly, on teachers' skills and beliefs." Leadership in academia tends to be older because of the traditional hierarchical promotion system, and industry professors are still rare, though not unheard of (for example, journalist Professor Peter Fray at the University of Technology Sydney in 2018). Whilst age is not a barrier to the adoption of new technology, it is arguably more difficult to adapt to new ways of working when expertise is built on traditional working practice. Large scale operations, such as universities, are difficult to redirect. Examples of disruptive change brought about by management decisions can be seen at the University of Melbourne though, for example, where first year studies were integrated, and trimesters introduced. Brown and Alder (2008) introduced "Learning 2.0," linked to the Open Educational Resources (OER) movement:

In a traditional Cartesian educational system, students may spend years learning about a subject; only after amassing sufficient (explicit) knowledge are they expected to start acquiring the (tacit) knowledge or practice of how to be an active practitioner/professional in a field. But viewing learning as the process of joining a community of practice reverses this pattern and allows new students to engage in "learning to be" even as they are mastering the content of a field. (Brown & Adler, 2008, p. 20)

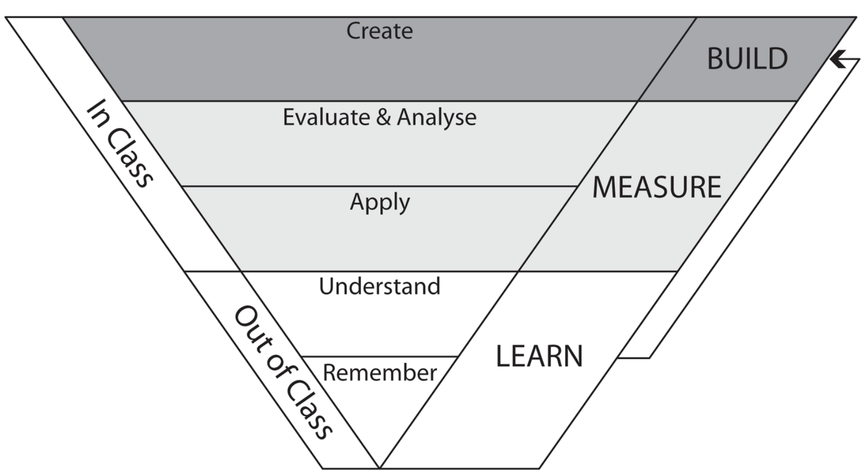
This prepares students for lifelong learning. In many ways this idea is more closely linked with an apprenticeship for design whereby learning is practice-led and conducted in the process of designing – thus learning and designing become intertwined (Novak, 2018). However, the rapid pace of change and the radically different ways of working that are emerging with Industry 4.0 require more proactive strategies than relying on current practitioners to lead the generation. Arguably it will be the other way around, as young people elect entrepreneurial practice over conventional employment, influenced by the success of companies such as Google, which started in a garage in 1998 and has 4.2 billion search requests daily in 2018, and YouTube, which started in a room above a pizzeria in 2005 and today has 8.8 billion videos online (Seldon & Abidoye, 2018). According to Seldon and Abidoye (2018, p. 137) "the IoT facilitates the collection of big data on a scale we are still unable fully to assess or exploit, as the sheer volume can militate against sifting the quality from the unreliable evidence and forming solid conclusions," and China is working to establish itself as the world's primary AI innovation center by 2030 (p. 314). Relying on conventional innovation practices within established industries responding to the challenges and opportunities of Industry 4.0 seems a dangerous strategy for the rest of the world. However, the rise in interest in entrepreneurship (for example 40% of students at the University of Technology Sydney expressed a preference for being an entrepreneur over being conventionally employed (Conroy, 2016)), and the opportunities to foster it that digital connectivity provides, may provide new direction. In order to maximize this trend, the university system needs to become nimble in its offerings, dynamic, connected and practice-led. This can only be achieved with a framework of practice to support academics in moving to this new way of thinking.

Responding to these changes, a proposed model of education that blends elements of the flipped classroom model (Altemueller & Lindquist, 2017; Gavriel, 2015) with a 'Build-Measure-Learn' lean startup approach may offer an appropriate strategy whereby students take responsibility for their own learning, guided by a facilitator. This is diagrammatically shown in Figure 1. The traditional roles of teacher and learner are reversed, with students bringing new knowledge to classes, which is disseminated to fellow students and facilitator alike. This is significant in a time where technology is evolving so rapidly that it is impossible for a single lecturer or facilitator to know everything. Combined with a lean startup approach, students are encouraged through projects to consider their products as part of larger business models, analyzing investment strategies, testing prototypes on the market, and even developing Kickstarter campaigns (for example a course called Innovation and Entrepreneurship run by the authors at Griffith University). This approach is agile and sets students up with lifelong learning skills as they participate in the practice of learning alongside peers and mentors.

The industrial design discipline by definition is about imagining, planning and realizing the future. Even when engaged with rationalizing the details of a specific manufacturing requirement for an individual company, the designer is part of a discipline focused on innovation, understanding and effecting progress. As designers will constantly face new challenges, new technologies and changing aspirations for society that impact design decisions, design education necessarily needs to prepare graduates to be lifelong learners and proactive, critical thinkers. Lynam and Cachia (2018) argue that in an increasingly digital, interconnected world, information is readily accessible and becomes rapidly outdated, and therefore future employers will value graduates who are critical thinkers rather than just knowledgeable. They highlight the ability to source and evaluate credible information as necessary for effective problem-solving and decision-making, and these skills are an important part of the framework described by Figure 1 as "out of class" activities. Sterling (2015) also argues that in preparation for real-world, complex problem solving, students need to be educated not about change, but rather *for* change and this requires a pedagogical shift from transmissive education to transformative education.

In the early decades of the twenty-first century, digital technologies are disrupting traditional business and industrial practices. Online communication platforms are fostering more realistic entrepreneurial ambitions than were previously possible, ubiquitous computing and the Internet of Things are forcing a complete rethink of product service systems, and additive manufacturing and the digitalization of inventory are enabling global distributed manufacturing. Whereas the development of industrial and product design practice over the last century could be characterized as incremental, building a body of

Figure 1. Proposed framework of learning based on the flipped classroom and lean startup 'build-measure-learn' models (Novak 2018)



knowledge on production practices and materials that informed design education, recent developments are creating a paradigm shift in the place of design in society and the role of the designer that contrasts with accepted practice. As digital disruption increasingly challenges established hierarchies and conventions, educational conformity may itself be under threat and traditional disciplines may benefit from a rethink on the role of product design education. Only, however, if product design education itself recognizes the emerging opportunities for change and breaks away from the constraints it has accepted will it gain acceptance in the current academic value system.

AUTHENTIC LEARNING IN THE TWENTY-FIRST CENTURY

Schools and universities in 2018 are little changed from 1600, for all the ubiquitous (non-AI) technologies. The teacher or lecturer address rows of students from the front of the class, who advances at the same pace. Learning is not personalized and the teacher is weighed down by the burden of preparing material, setting and marking assignments, and reporting on student performance. (Seldon & Abidoye, 2018 p. 140)

As university funding has changed, so have university student numbers increased. The organization of university education, its monitoring and regulation, have become driven by administrative realities that are created to work across large organizations. There are advantages in this approach, for example the ability for students to work more easily across modular programs to differentiate themselves through specializations, and the ability for students to retake single subjects or study part time in order to support themselves financially or negotiate other external commitments. However, the overall result is the modularization of the learning experience. Academics have to break learning into distinct events. The student is expected to put the experience together in their own minds to become well rounded graduates. It is clear from the rise in importance of graduate attributes from a university perspective that there are concerns already with this approach, and considering the large body of educational research arguing for authentic learning in recent years (e.g. Dee Fink (2013), Weimer (2013)), it is important to question whether organizational constraints are in fact distilling the educational experience. Before modularization, design was predominantly taught as a series of projects. If research shows that this approach is more effective for design teaching in the twenty-first century, will universities support the change? If the modularization of learning for administrative reasons was set to one side, and an objective, fresh view of design education in the current context, post digital revolution, with the growing sustainability imperative and the need for contraction and convergence and extended producer responsibility, what would it look like? Is the future of product design compromised by the conventions of past learning at a time when a paradigm shift in human patterns of consumption is needed and new thinking is required? As Gore discussed in his book *The Future* (2013, p. xv)): “There is a clear consensus that the future now emerging will be extremely different from anything we have ever known in the past. It is a difference not of degree but of kind.”

Design academics need to engage more intensively with research into learning to build a new body of knowledge specifically on design teaching for the twenty-first century. It may be that teaching intensively in short bursts over the year best prepares students for the stresses and pressures involved in their role as designers in the future, or it may be that providing no factual knowledge to students during their degree is a strategy, where they have to gain first-hand knowledge of factors, such as materials and processes, at every level.

Students need to prepare for individualized learning programs. Schools and universities have to catch up with their students quickly. Equally, they must prepare for life-long learning, which will spread rapidly. Credit transfer will become the norm rather than the exception. Students should all be taught computer, digital and AI literacy, and how to understand the difference between the human and the machine. The Welsh government is ahead of other UK nations on this. (Seldon & Abidoye, 2018. p. 313)

Research into design studio assessments needs to challenge the underlying assumptions that tertiary educational accountability builds in. It may be that assessment should never be based on the individual, that a more genuine engagement in teaching group work and differentiating roles is essential for effective operation as a designer in the future. This may include the use of online hubs to bring together geographically separated individuals to work collaboratively, rather than relying on the traditional physical classroom, with Massive Open Online Courses (MOOC's) and collaborative websites like GitHub, providing new ways for individuals to learn and engage in real-world projects. Design is a real-world activity, and assessments will have more meaning for the students if they are current and real-world relevant. According to research by Lynam and Cachia:

Student-focused assessments were preferred by students and encouraged engagement. Learners appreciated assessments that built on their skill set; involved an element of choice and creativity; and were associated with a balanced workload. Students particularly valued the benefit of having assessments that were relevant to their career ambitions and developed their skill set. (Lynam & Cachia, 2018, p.231)

The disruptions that technological developments are creating in the world need to be acknowledged in university industrial and product design education. The disciplines need to throw off the academic cultural cringe that has resulted from coming late to an established game, with rules that did not take them into account, and competing on a playing field that is far from level. This is not for the sake of the disciplines, but for future generations who need the benefit of design education that is not watered down but has genuine integrity that responds to the context it is constructed within. This century is crucial for the future of mankind and the health of the environment. Designers are needed, and design academics must prepare.

There is a dominant link in education between the idea of interdisciplinarity in education and industry 4.0. Seldon and Abidoye (2018) argue for problem solving, open ended problems, collaboration and the reduction or delaying of specialization. In design, project-based learning is common-practice in higher education, and the concern Seldon and Abidoye express over the dominance of 'right' answers in education does not realistically apply in design as there are rarely 'right' answers. Projects are already commonly marked based on process as much as, or instead of, end products. Interestingly, interdisciplinarity is more contentious. Whilst it is frequently argued that projects break disciplinary boundaries and require an interdisciplinary team, it is more difficult to teach in this way across disciplines beyond merely bringing students from different domains together. Transdisciplinary programs, such as the ones run at the University of Technology Sydney, appear to work well for service design problems. However, if the focus is on Industry 4.0 and preparing for the future role of product designers to work within the subsequent systems, there are some differences. The reality is that, just as earlier manufacturing processes had constraints and opportunities, so too do the processes within the systems of Industry 4.0. There are difficult technical challenges in designing for these production processes, for example for additive manufacturing; this is a challenging technology to design for and if it is not taught properly it will become solely the domain of engineers using topological optimization software, or growth software using algorithms capable of 'designing' products automatically without the need for designers at all. Further changes are affecting the communication of concepts, with renderings taken from CAD programs replacing concept drawings, and virtual reality experiences emerging to replace these renderings.

Product designers need to change their thinking to looking at the industrial system, the product service system but also now the full life of the product which itself can change over time through embedded electronics or 4D materials. The idea of a static product has been debunked because of the agency attached to it. Culturally products have impact, and the future of work and industry is impacted by design. As Rosling, Rosling and Rosling Ronnlund (2018) point out, the current worldview is outdated and many people are working on incorrect facts on important issues, such as crime statistics, healthcare costs and employment statistics: "Would you be happy if your doctor was using cutting-edge research from 1965 to suggest your diagnosis and treatment?" (Rosling, Rosling, & Ronnlund, 2018, p. 26). According to Cameron (2017) and Bregman (2017), the worldview has to change in response to the digital revolution. Industry 4.0, encompassing AI and machine learning, will change not only the organization of labor but also its nature: "It's time for a new labor movement. One that fights not only for more jobs and higher wages, but more importantly for work that has higher intrinsic value" (Bregman, 2017, p.261). Academics need to recognize this possibility and address it within higher education in all disciplines, and product design is no exception.

RECOMMENDATIONS

Raising the next generation of designers requires academics to question current educational models, practice and content. The impact of Industry 4.0 on their educational experience should be radical, not incremental, yet this is difficult for academics immersed in current systems and ontology. In preparing students for a future in design, academics need to focus not solely on skills, but on preparation for lifelong learning, and, more essentially, for understanding their role in human development in a digital era. An educational framework for the emerging discipline is suggested, based on key points summarized here:

Table 1. Proposed framework of learning based on the flipped classroom and lean startup 'build-measure-learn' models

Learning From History	Learning From the Present	Learning for the Future
Reduction in poverty through industrialization	*Widening educational access and changing educational models*	*Lifelong learning and agility in educational offerings*
Social planning problems due to centralized manufacturing	*Fragility of policy and political decisions*	*Distributed manufacturing*
Impacts of pollution and the failure of current systems	*Extended producer responsibility*	*Circular economy*
Waste of natural resources	*Product service systems*	*Entrepreneurship*

This chapter addresses issues relating to disruptive change for higher education signified by Industry 4.0, using the product design discipline as an example, and outlines the paradigm shift needed for education to remain relevant. It highlights the importance of education that integrates the humanities with engineering for the future of society and draws on a historical perspective of the impact of societal and environmental change brought about by earlier industrial initiatives. Through this approach, the chapter calls for a greater emphasis on human development in a digital era and environmental, social and economic responsibilities embedded in the implementation of Industry

CONCLUSION

Over the last twenty years, the proportion of the global population living in extreme poverty has halved. This is absolutely revolutionary. I consider it to be the most important change that has happened in the world in my lifetime. It is also a pretty basic fact to know about life on earth. But people do not know it. On average only 7 percent – less than one in ten! - get it right. (Rosling et al., 2018 p.6)

Product designers need to be non-conformists. They need to be able to consider the world and its systems with an informed objectivity, and not be held back by outdated ideas or knowledge that has been superseded. Based on the impact of mass production on the environment, and, in particular, the throw-away society of the twentieth century, it is interesting to consider how the benefit of hindsight could have altered production and disposal practices that characterized the era. Education on the cultural changes involved could have contributed to the development of different values and systems whilst change was in its infancy, and it was possible to influence its direction. Product designers need to be intrinsically motivated to keep updating their understanding of the world and their impact on it. It is the role of product design educators to foster that motivation by constantly questioning educational practice and engaging in pedagogical research. The future of work and industry will be very different in the way it operates to how it did last century. "Time is money. Economic growth can yield either more leisure or more consumption. From 1850 until 1980, we got both, but since then, it is mostly consumption that has increased" (Bregman, 2017 p. 139). The digital revolution is changing interaction, identity, community and economics. Universities as an institution are under threat with competition from open access education and alternative educational providers after the 2010 restrictions on for-profit private universities entering the sector were relaxed.

Coming late to the academic community, industrial and product design educators have strived for acceptance and credibility within established hierarchies and systems. However, from disruptive technology to disruptive ideas, the early decades of the twenty-first century are creating a period of paradigm change and design education should not align itself with entrenched, complacent ill-prepared academia. An educational rebellion is needed for design learning to remain relevant, and to shoulder its responsibilities not only in preparing the designers of the future, but also in leading a rethink of education that is not based on the assumption that accepted practice is unassailable and should not be challenged. As West observes, "regardless of the diversity of our actions, material desires, and well-bring, we all want to have meaningful and fulfilling lives" (West, 2017, p. 211). Pedagogy must be subject to constant critical, unbiased scrutiny and product design academics must never forget they are designers at heart.

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KEY TERMS AND DEFINITIONS

3D Printing (Additive Manufacturing): A digital fabrication technology that allows the production of an object by adding material layer-by-layer in three dimensions.

Computer-Aided Design (CAD): The use of computer systems to assist in the creation, modification, analysis or optimization of a design in 2D or 3D.

Flipped Classroom: This is a teaching methodology that encourages students to access lecture material outside of class, devoting class time to hands-on problem solving and the application of knowledge. The teacher's role shifts to that of a facilitator, and collaborative learning and problem-based learning are important features of the flipped classroom.

Industry 4.0: Also known as the "fourth industrial revolution," this describes the current trend for increased automation in manufacturing, communication and machine-to-machine and human-to-machine relationships more broadly.

Product and Industrial Design: Disciplines tightly linked to mass production and the design of goods to be manufactured for consumption.